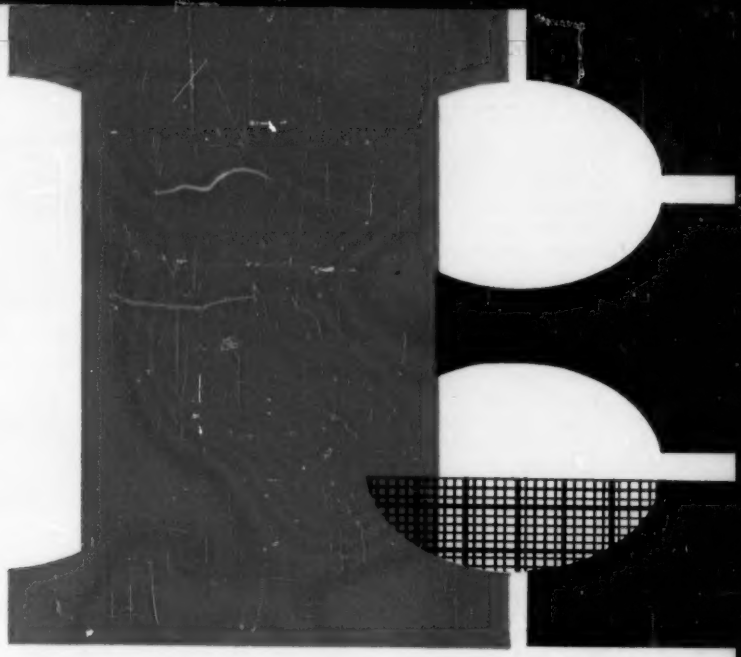

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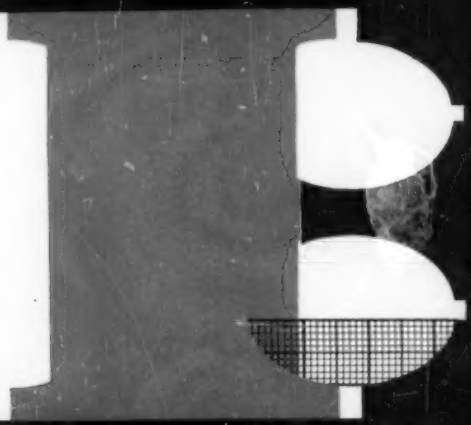

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System Simplification

by **W. SIDNEY TAYLOR***

Headquarters, United States Air Force

The Space Age, automation, complexity and bigness in business, industry and government operations have combined to create a new challenge and opportunity for top management—System Simplification.

LIKE the story of the little King who nightly stole out of his castle in beggar's raiment to ascertain the true condition of his kingdom . . . modern managements are finding it increasingly difficult to comprehend and control large scale operations. Big business and big government face a common dilemma. Operational complexity and technological uncertainty have combined to place a new burden upon management's ability not only to appraise, but more importantly to keep abreast in a Space Age environment.

As Goode and Machol outlined in their book *System Engineering* (4):

> The complexity of man's existence increases at a growing rate. Subjectively, this growing complexity would not have been noticed in the lifetime of a single man 200 years ago. Today, the comments of an older generation indicate amazement at the change in the pace and intricacy of life since their childhood. Even the observant young man of twenty-five will have noticed differences in rate and number of functions performed by the civilized man and by the American in particular. Objectively, this changing rate may be roughly measured by various statistics. There are more of us; we interact with one another more often; and we move with greater speed. We do more things, more kinds of things, and more difficult things.

However, complexity is only one dimension of the systems problem. A new tempo of change and uncertainty brought about by science and technology greatly compounds this problem. As J. Lewis Powell, author and lecturer, has pointed out (10):

> In 1830 a tremendous thing happened. Man broke the "oat barrier." He invented the steam engine. In one stroke, he replaced the oat burner with the coal burner. For the first time in 49,800 years he was able to travel faster than the muscles and digestive system of a horse. By 1910, the first military airplane had reached the incredible speed of 42 miles per hour. Towards the end of World War I we achieved speeds of 150 miles per hour. At the end of World War II, 470 miles per hour was a classified secret. Then in 1945, the curve of technology zoomed upwards on all fronts. By 1957, 1600 miles per hour was achieved and today we are talking about speeds of 25,000 miles per hour and space travel.

This rate of progress is not confined to transportation. Technological breakthroughs are also occurring in the fields of energy communications, chemistry, medicine, productivity, materials, and electronics. In order to keep pace with this new progress, a spiraling demand has developed for automation and automatic devices. Broadly defined as "buttons that push themselves," automation is creating a new way of life in office, factory and defense operations. Electronic computers, automatic data processing and "real time" feedback devices have become basic to big business and big government operations.

Underlying this trend is an increasing awareness by top managements that automation and control devices, although important, constitute only one dimension in total system management. A growing danger in office and factory automation is the present tendency of many top managements to substitute automaticity for imagination and creative questioning about the basic objectives, principles and operations of the business or enterprise. In some areas, there are indications that "inefficiency" is often being replaced by "instant inefficiency."

Installing an electronic instrument panel in a 1925 Maxwell, for example, will not increase its mileage or speed. This applies to a corporation, an airplane or a government agency. Someone must also lift the "corporate hood" and inquire into how and why the various components or cylinders of the system operate. The weakest link in a corporation or organization may not be its data processing or controls, but rather the inability of its top management to see (even with automation) new operational opportunities and combinations which can significantly change the nature and progress of the business itself. For this reason, system analysis preliminary to automation has become an important, if not critical, management technique. According to John Diebold leading automation consultant (2):

> The real conflict between long-term management planning and the short-term profit squeeze is vividly displayed today as companies wrestle with their computer programs and their automation investments. They are paying the price of too much fascination with the hardware of automation and too little understanding of its management implications and basic organization changes that are needed to make it work. . . . Automation is much more than just a technical problem. Purely technical matters do not usually faze modern business. But automation confronts management with a change in organization and approach.

This change in approach is most dramatically illustrated in weapon systems. Weapon automation (the missile is basically an automated aircraft), plus technological speedup has necessitated a total system management philosophy simply to insure integrated control of the vast resources involved. At the same time, a growing

---

*The author is a civilian employee of Headquarters, United States Air Force. He has been a member of various Industrial Engineering, personnel systems and weapon systems management groups. He has also worked with the Department of Commerce, Public Health Service and in private industry. However, the views and opinions expressed in this article are solely those of the author.

FIGURE 1

trend toward complexity is indicated by rising costs. At the end of World War II, the B-29 bomber cost around $600,000. Today's B-52 bomber costs around 8 million dollars. In missiles and spacecraft, costs may involve as much as 100 million dollars per vehicle. In any case, a total space or weapon system including bases, personnel, maintenance and supply is a billion dollar operation.

WHY THE NEED FOR SYSTEM SIMPLIFICATION?

Complexity, big risk and system obsolescence are not limited to weapon or space systems (Figure 1). This problem presents itself in business, industry and government (non-defense) operations. At least, forty-nine American corporations are now in the billion dollar sales or revenue category. One thousand American corporations have assets of 100 million dollars or more. Many of today's business executives find themselves making at least one decision a year having million dollar (megabuck) implications.

Ford Motor Company, for example, had a 250 million dollar investment in Edsel before it was phased out after a two year run. Howard Hughes obligated 320 million dollars in a decision to acquire sixty-three jet aircraft for Trans World Airlines. Radio Corporation of America has invested more than 130 million dollars in color TV over the past ten years.

These are king-size examples. However, they reflect a growing trend toward big risk, fast moving technology and rapid system obsolescence. In many areas, management's ability to promptly respond to new circumstances, competition or opportunities is seriously challenged. Efficiency engineering at *work* levels is often overtaken by *system* or top management events. *System* level decisions, modifications, or breakthroughs tend to make obsolete thousands of subordinate *work* level processes, procedures, or components before they can be standardized, simplified or automated. In this environment, many organizations find themselves "polishing brass on ships already sunk by technology."

In George Washington's day, for example, canal stocks were a "blue chip" investment. They provided the most effective means of cargo transportation. However, railroads (twin streaks of steel instead of a canal) introduced a more flexible and simplified system which ended the canal era. Today, the automobile and airplane are overtaking the railroad. By 1965, missiles may introduce entirely new concepts of transportation. Without technology it is possible that we might today have a super-efficient, even automated, system of canals crisscrossing the entire United States. Fortunately, this never happened. However, it underscores the growing need for combining the "know-how" of science, technology and management into a common team. This is one of the basic objectives of System Simplification.

WHAT IS SYSTEM SIMPLIFICATION?

System Simplification is a Space Age management concept designed for application to large scale organizations or man-machine systems. As a modernized approach in the management field, it constitutes a synthesis of principles and techniques borrowed from Operations Research, Industrial Engineering and Systems Engineering (Figure 2). It is equally applicable in improving the design or operation of weapon, logistic, product or administrative type systems. As a tool, it is oriented toward improving executive skills and comprehension at system levels . . . preliminary to developing management or product improvements, conducting reorganizations, installing automation or designing automatic data processing systems.

In a comparative sense, System Simplification is a direct expansion upon principles long employed in Industrial Engineering and Work Simplification (7). However, compared to Work Simplification, System Simplification is simplification not only at a different *level* of management; it is a different *kind* of simplification (Figure 3). While Work Simplification is directed toward methods, work processes and office or factory productivity, System

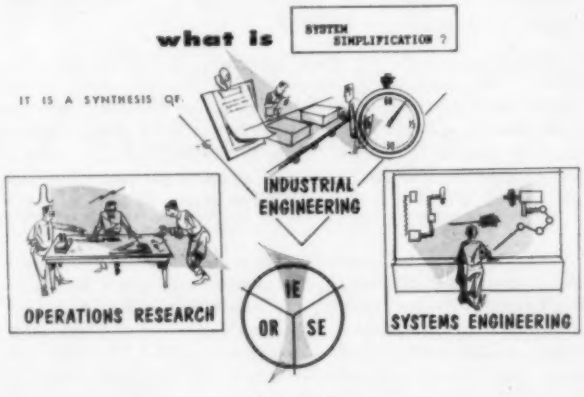

FIGURE 2

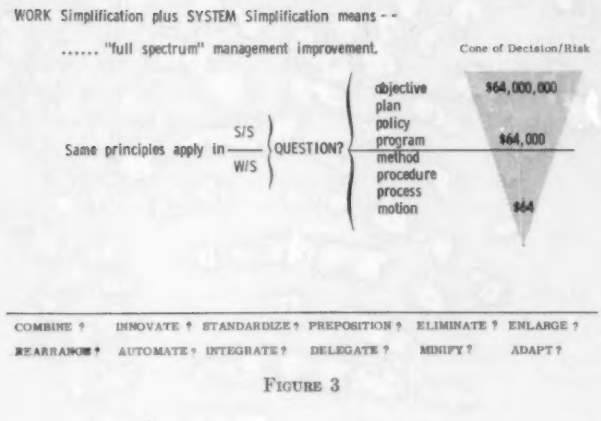

FIGURE 3

Simplification is oriented toward simplification of total business objectives, plans, policies, operations, controls, etc. However, System Simplification does not replace Work Simplification; it complements it. In effect, System Simplification begins where Work Simplification leaves off (Figure 4).

In improving the design and operation of large scale systems, System Simplification emphasizes the development of executive skills at conceptual levels. In this sense, it is not a *training* program. Rather, it is a program of executive *education* oriented toward improved knowledge and comprehension of the phenomenon of large scale man-machine operations. System Simplification is not designed to streamline or simplify methods, procedures or work processes. It is designed to simplify—if not revolutionize—entire programs, operations and functions at top management levels. For this reason, the primary objective of System Simplification is the development of a frame of mind at top management levels which encourages new perspectives and innovations in approaching system problems and opportunities.

PRINCIPLE OF SIMPLICITY

In industry, business and government, simplicity has been an important part of the scientific management movement for the past fifty years. Frederick W. Taylor, the Gilbreths, Allen Mogensen and other leaders in Industrial Engineering have substantially proven the merits of simplicity at work and production management levels. However, Space Age technology and time compressions have focused greater attention upon the potential of simplification at top management levels.

In System Simplification, simplicity is considered a primary top management objective (see Figure 5). Simplicity is applied in its widest context to "total" business objectives and operations prior to simplification of procedures or processes at work levels. Automation, mechanization or standardization are secondary goals. Underlying this concept is a recognition that simplicity is not only a primary principle of war (11), but also a principle of managament (8), and a vital factor in conducting effective Operations Research (1).

In designing new and more effective systems (weapon, product, logistic or administrative) the systems executive or engineer must be simplicity-minded. He must continually orient himself toward doing the job with purposeful objectives, least number of components, uncluttered organization and control structure, and the minimum investment, expenditure, or risk of resources. Underlying this assumption, is the fact that simplicity in itself tends to improve other system characteristics such as economy, efficiency, control, accuracy, reliability, maintainability, producibility, flexibility, etc.

WHAT ARE THE "TECHNIQUES" OF SYSTEM SIMPLIFICATION?

The techniques employed in System Simplification are oriented toward inducing new perspectives in decision-making at top management levels. While only briefly outlined in this article, three phases are involved: *documentation, simulation,* and *interrogation.*

SYSTEM DOCUMENTATION

Modernization or improvement of any large scale system depends in a large measure upon knowledge concerning the operation of the total system itself. It is important to first have some idea as to *why* and *how* the system operates. In order to comprehend, let alone improve, a large scale system involving thousands of "man-machine-environment" relationships, it is necessary to portray or document at least the primary objectives, structure, components, workloads and resources involved. This introduces the expression "system comprehension." Not unlike the electronic engineer who must breadboard or diagram complex circuitry, the systems engineer must document all significant elements in order to facilitate conceptual understanding by all concerned.

While management and Industrial Engineering authorities have long discoursed on "span of control" as applied to organization structure, a similar problem, magnified many times over, exists in "system comprehension" as

SYSTEM SIMPLIFICATION — Comparative Techniques:

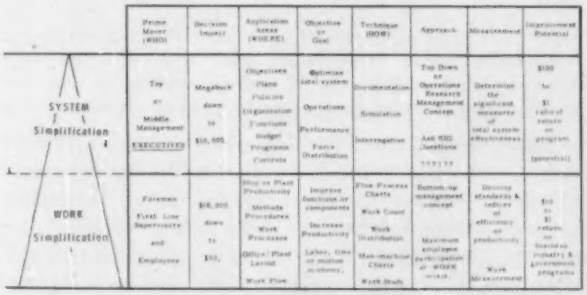

FIGURE 4

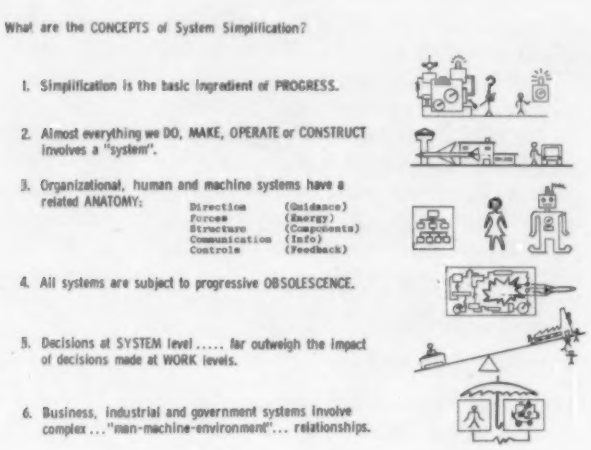
What are the CONCEPTS of System Simplification?
1. Simplification is the basic ingredient of PROGRESS.
2. Almost everything we DO, MAKE, OPERATE or CONSTRUCT involves a "system".
3. Organizational, human and machine systems have a related ANATOMY:
Direction (Guidance)
Forces (Energy)
Structure (Components)
Communication (Info)
Controls (Feedback)
4. All systems are subject to progressive OBSOLESCENCE.
5. Decisions at SYSTEM level ..... far outweigh the impact of decisions made at WORK levels.
6. Business, industrial and government systems involve complex ..."man-machine-environment"... relationships.

FIGURE 5

applied to large scale operations. A weapon or space system may involve 100,000 interacting components. A paper-work or accounting system in a large corporation may involve similar complexity.

Documentation will vary with the nature of the system. Among the techniques employed are: organization and function charts; manning or position charts; cost distribution charts; workload or workflow charts; production process charts; plant or office layout charts; information or data flow charts; performance or profit graphs, etc. While only the beginning of a progressive process of more sophisticated investigation into system operations, charts and pictorial aids constitute an important stepping stone toward total system comprehension. Mr. Warren E. Alberts, Vice President of Industrial Engineering, for United Air Lines, recently outlined their importance (14):

> Success in operating or maintaining a business system depends on one's understanding of how it actually operates, what its basic objectives are, and the ability to measure its operation. One of the problems is that most business systems thread through many departments and although each department has a fair understanding of how its portion of the system operates, no one has a clear picture of the whole system and how these pieces are interacting with one another.
>
> Sometimes the biggest gains in the operation and maintenance of a system are derived simply through the flow charting of the entire system regardless of how many departmental fences it may cross. In many companies this presents a real problem because the systems group reports to one operating department and is not free to pursue system problems with other areas. However, it is only through this type of over-all charting that a clear understanding of how a system operates can be obtained.

The United States Air Force, for example, recently established "Panel Rooms" using 40 by 60 inch wall charts to present a panoramic picture of worldwide weapon system operations. These rooms reflect at one focal point the entire spectrum of management concerning billion dollar weapon systems. Included are programming charts, unit locations, numbers of air vehicles per squadron, manpower and budget requirements. Problem areas are identified, and "get well" dates assigned.

However, these rooms involve more than problem solving or the pictorial display of statistics. They constitute a valuable monitoring device for bringing project officers, data and ideas together at one point. Periodic reviews are conducted by working groups concerning weapon system performance, costs and combat readiness. This not only tends to increase awareness of new technology and operational changes, but most importantly, insures integrated responsiveness to management problems and opportunities as, or often before, they occur.

A similar approach has been employed with considerable success in industry. DuPont in Wilmington, Delaware, has established a theater-like chart room where top management can, at a glance, see the significant data and trends concerning the corporation's total operation. This involves 400 framed charts each suspended from overhead tracks. Charts are rolled into position in a matter of seconds. Another example is United Air Lines' "room with the 14,000 mile view" at Denver. This control room was so named because it gives United Air Lines' executives a pictorial perspective of total system operations including daily airline traffic and corporation profits.

System documentation produces a unique psychological by-product. It tends to induce new perspectives, ideas and improvements at top management levels (Figure 6). Awareness of total system interactions and performance has a profound impact upon decision-making processes. Innovation, creative thinking or brainstorming techniques have expanded potential when top executives have a complete picture of system operations. The importance of documentation was recently outlined by Mr. Richard W. Pomeroy of Fairbanks Associates, Inc. (6):

> Graphic presentation is to the systems profession what a numbers system is to the field of mathematics—a language of abbreviation enabling the understanding of complex phenomena in relatively short periods of time.

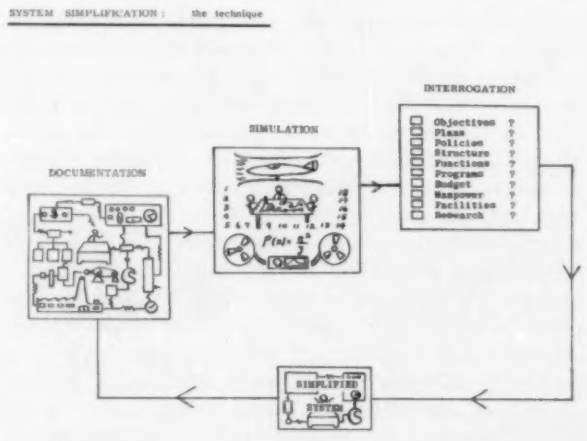

FIGURE 6

Charting is by no means the sole province of the systems function. It is an integral part of the activity of almost all professional techniques, a heavily relied-upon device for simplification and presentation in hundreds of different contexts. But outside the field of pure science, few areas rely so much on the use of graphic presentation as does the systems profession.

Many of today's industrial, business or government-type systems involve million or even billion dollar investments. At this magnitude, it is important to recognize that a single *system* improvement, modification or decision can eliminate the need for 10,000 procedures, actions or simplifications at *work* levels. The most effective way to simplify (and reduce costs) is from the top down. For this reason, total system documentation becomes a powerful tool and primary step in System Simplification.

SYSTEM SIMULATION

An indefinite line demarks the point where documentation ends and simulation begins. System documentation is largely the pictorial (and static) representation of total system operations. By comparison, system simulation or model building generally reflects the organization in quantitative (and dynamic) form. In this process, performance can be measured and it is possible to "manipulate," "test" and "price" improvements on paper, or in small scale form, without risk, costly investment or interference in actual operations.

Model building is not new. It is used in many branches of science and engineering. Prototypes, plant layouts, laboratory setups and wind tunnels are all forms of model building. However, electronic data processing has opened up entirely new possibilities for the simulation of an entire business system or enterprise. United Air Lines for example, has simulated the routing and maintenance of their entire aircraft system. This project, which is probably one of the largest business models in the world, required more than two years to develop. However, they can now simulate 100 days' operation at a station like New York in less than 10 minutes. This has led to other models concerning ticket counters, scheduling of manpower and aircraft engine overhaul. The Rand Corporation in California conducts worldwide war games involving aerospace battle simulation in mathematical model form on electronic computers. In the business games area, the American Management Association in New York conducts decision simulation training courses for top corporation executives (13).

Model building to simulate the interaction of men, machines, money and material in a large-scale business or industrial system is a relatively new development. Every manager has at least four models which simulate or represent the operations of his business or enterprise. One is *economic:* the accounting system, profit and loss statement, etc. A second model is *social:* the organization chart reflecting the people who manage the various functions. A third model is *physical:* the plant, machines, work layout, tools, materials, etc. A fourth model is the *information* system. Not unlike the human nervous system, this model is the keystone to effective integration, control and feedback for total business operations. It generally reflects information inputs, data flows, processing and outputs in report or record form which in themselves tend to guide or influence decision-making processes at all levels of operation.

While important, model building or simulation is only one step in a progressive process of total system investigation. It is equally important to observe actual operations and ask leading questions on how and why a system operates the way it does. This introduces the last, and one of the most important phases of System Simplification—system interrogation.

SYSTEM INTERROGATION

Some of the most dramatic improvements in large-scale organizations have been the result of relatively simple questions applied at top management levels. Contrary to a large segment of modern management thinking, it is not always necessary to conduct long, costly, efficient engineering studies "from the bottom up" in order to substantially improve or modernize a large-scale system. The right question at total system level can often uncover dramatic improvement potential. This requires an imaginative skepticism about total business objectives, plans, and operations at "throne room" level. When this attitude is achieved, skillful interrogation can often reveal real opportunities and surprises for top management.

System or business interrogation assumes many forms and shapes. It may be described as a "systems survey" or a "management audit." In any event, it involves orderly inquiry into the objectives, plans and operations of the total business or enterprise. Interrogation complements documentation and simulation by providing a panoramic review of those elements in the system which can not be easily portrayed or quantified. This includes those non-physical, and often ill-structured, elements as business objectives, policies, plans, executive motivations, competitive strategy, etc.

The American Institute of Management in New York, for example, has developed a management audit checklist which includes a series of 300 questions designed to appraise the effectiveness of a large organization (12). Developed by Mr. Jackson Martindell, this technique includes a 10,000-point evaluation system which has been used to rate such varied activities as religious organizations, colleges, hospitals, institutions and large corporations. Metropolitan Life Insurance Company, Department of the Army, and other large organizations and consultant firms have developed similar techniques. In any event, the audit outline or survey checklist must embody questions carefully selected to fit the nature of

the particular enterprise, operation, or system being studied.

Much of the potential in system interrogation is due to the fact that many of today's large-scale man-machine systems start becoming obsolete from the moment they leave the drawing board. A 1960 airplane designed with 1910 components would be a costly, if not dangerous, vehicle to operate. Nobody would want to fly it. However, many of today's government, business and industrial organizations are built around similar componentry. In many cases, obsolete policies, plans, or methods are buried or obscured under decades of organizational inertia, protocol, or custom. Costly policies or operations are not only adopted, but standardized (and worse still, in some cases—automated). This is largely the result of top management's inability to comprehend total system objectives, operations, and interactions.

Around 1956, a large east-coast corporation decided to study their maintenance function. The final report indicated that modernization of the maintenance function had resulted in a 2 million dollar annual saving for the corporation. Everybody was pleased. In fact, several top executives were promptly promoted. This should have been the ending of a happy story. However, by 1959, the corporation president was shocked to find that his improvement in maintenance had resulted in an unexpected 6 million dollar increase in the supply budget. After a million dollar loss, they quickly and quietly returned to the old system.

This is a king-size example of the high cost of "piecemeal" management improvement. Nevertheless, it is happening every day in business and government. The solution is a full awareness of the economic and operational interaction between major functions and programs. This is best achieved by adequate documentation, simulation and *interrogation* of total operations.

However, like the courtroom manner of a prosecuting attorney, system interrogation is a real art. It involves much more than simply asking questions. The real skill revolves around asking *big* questions. This was brought out by Mr. Cecil E. Goode in his book *Personnel Research Frontiers* (3).

EXECUTIVE SKILLS:

The human component in man-machine systems

Area	Skill	Characteristic
Managing the BUSINESS	Conceptual (ideas)	Ability to see the enterprise as a whole; achieve an optimum balance in objectives, plans, policies, controls, functions, forces, structure, strategy, etc.
Managing PEOPLE	Human (people)	Ability to work with and through people. Understanding of human motivations and attitudes. Leadership skill in terms of people.
Managing WORK	Technical (things)	Ability to work with things (as opposed to people), hardware, equipment, tools, materials, data, machinery. Leadership skill in terms of technique-engineering.

FIGURE 7

> Although there is some important and very intriguing research being done on the human problems of organization, there is still too much fragmented empiricism. Social science researchers pursue easily-tackled problems. As one respondent, a public administration practitioner, said, "Social scientists don't ask big enough questions. Therefore, they don't come up with very big answers."

This problem is not limited to the social sciences. It applies in product, weapon, logistic or paperwork system evaluation. Executive skills must include an ability to ask *big* questions. This tends to cast a long shadow across the *think* signs now hanging in many top management offices. A more appropriate sign may well be: "Don't *think*; ask *big* questions first!"

IMPORTANCE OF EXECUTIVE SKILLS

Social, economic or technological progress is the product of human (not machine) skills and leadership. Machines or systems do not improve themselves. The real prime mover or "self starter" is man himself. There is no substitute for human leadership.

Space age management requirements have placed a new spotlight on executive skills. Modern executives face increased difficulty in comprehending and orienting to new conditions, forces and knowledge. Ability to ask *big* questions, *think* and innovate has become fundamental in the design and operation of large scale systems.

The importance of conceptual skills has been outlined by Dr. Robert L. Katz of Harvard University (5):

> At lower levels of administrative responsibility, the principal need is for technical and human skills. At higher levels, technical skill becomes relatively less important while the need for conceptual skill increases rapidly. At the top level of an organization, conceptual skill becomes the most important skill of all for successful administration. A chief executive may lack technical or human skills and still be effective if he has subordinates who have strong abilities in these directions. But if his conceptual skill is weak, the success of the whole organization may be jeopardized.

This does not infer that a few persons at top management level can direct an organization without feedback and participation from others skilled in human and technical aspects. However, it does indicate three distinct categories of leadership (Figure 7). A business, operation or system exists in three dimensions as an aggregation of people, things and ideas. In this sense, the ultimate science is not physics, mathematics or chemistry but management itself. The crossbow craftsman of 1260 and the missile engineer of 1960 have much in common. Both jobs require technical skills. However, the development of new hardware, forces or weapons will mean little if it is directed by inadequate or outdated management know-how at conceptual levels.

The new challenge is not in productivity, speed or

power. Surpluses are appearing in many areas: speeds of 18,000 miles per hour are commonplace; nuclear energy offers unlimited power. The new challenge exists in achieving order and balance between the vast forces, and complex componentry of modern, large-scale industry, business and government operations. Improvements at procedural levels are not enough. It is possible to have methods, office or plant layout, or worker productivity at 100% efficiency—in a system which itself is sub-essential, obsolete or ill-conceived. This is where executive innovation and imagineering come in. There are no pat answers. Each situation has its own set of variables. This is the real test of executive skill and leadership.

AREAS OF APPLICATION

While System Simplification has broad application in business or industry, its greatest potential exists in government operations. Many of our Federal institutions are based upon assumptions, laws and concepts generated in an era of button shoes and gaslights. The present Civil Service System, for example, is based upon the Pendleton Act of 1883. Our post office, judicial, legislative and fiscal systems have similar, if not older, origins. Many of our Federal regulatory, taxation and economic concepts were conceived generations ago as temporary or one-time emergency measures. The result is an evolution of components or controls which are often unrelated to the needs or logic of the total system. Congressman Wilbur D. Mills, Chairman, House Ways and Means Committee, recently outlined this problem in the tax area (9):

> Our tax laws—revised each year, with something added here, something subtracted there—are like some fantastic building on which a dozen contractors have been working at once, each from a different blueprint. The laws have long since lost sight of the real purpose of taxation, which is simply to raise the money the government needs to pay its bills. They are full of contradictions and inequities and are totally inadequate to do the job of raising the tremendous revenues our government needs.

This problem is not limited to taxes. Similar situations exist in legislative, judicial, economic, labor and defense systems and programs. The real challenge (Soviet and otherwise) exists not in missiles or technology, but in the area of Federal management. American know-how in business and industry will progressively be forfeit if it is not matched by equal imagination and innovation in Federal operations. Misgovernment is the deadliest form of mismanagement.

THE CHALLENGE OF PROGRESS

The challenge of the Space Age is unique in human history. On one hand, we are about to enter a golden era of power, speed and productivity that is unparalleled. On the other hand, we are confronted by ominous signs that man is becoming the victim, rather than the beneficiary, of his own ill-managed progress.

In the transportation field, for example, 40,000 Americans are killed each year by that deadliest of all peacetime man-machine systems—the automobile. Much of this slaughter continues due to an inability to comprehend and improve the vast "man-machine-environment" relationships involved.

A similar situation is developing in administrative systems. Growing complexity and red tape in taxation, social security, unemployment and health insurance, labor laws, interstate and foreign commerce, economic controls, etc., threaten to convert us into a nation of clerks. In 1900, one employee in forty was a clerical worker. In 1959, this ratio was one in six. New laws and regulations (Federal and State) are generating paperwork complexity that challenges even the most modern of electronic computers.

In product systems, Americans face a new poverty of plenty. Automobiles, televisions, electric appliances, telephones and a thousand other stimuli exact a hidden toll in human time, tension and maintenance. In a gadget-cluttered, machine-dominated society, people have little time for life, liberty or the pursuit of happiness. Most importantly, they have little time to ask *big* questions about an environment that causes 20,000 suicides annually, puts mental disease as the occupant of one out of three hospital beds, creates juvenile delinquency in one out of five American youths, induces 900,000 heart attacks, consumes one-half billion tranquilization pills—and then comes up with a national debt of 290 billion dollars.

These are not symptoms of procedural problems, but total system problems. Solutions involve a need for "managerial" rather than technological breakthroughs. In this process, is it possible for simplification at system levels to revolutionize an entire business or industry? The answer is, "yes." In fact, it is already happening in business, industry and government. The transistor, electronic computer, guided missile, printed circuitry, solid state physics, nuclear power, polio vaccine, etc., are all examples of technological breakthroughs having total system impact. Similar opportunities exist in economic, social and government systems improvement.

Progress, however, is not achieved by technology alone. The real prime mover is not things but people. A business, industry or government is run by its managers. Once these people achieve a better understanding of business objectives, forces and "man-machine-environment" interactions, it is possible that revolutionary new policies, concepts and quantum-like innovations can be achieved. This is the primary objective and purpose of System Simplification.

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Contributed Research Papers for the Twelfth Annual National Conference

A session at the Twelfth Annual National Conference of the American Institute of Industrial Engineers, in Detroit, Michigan, on May 11 and 12, 1961, will be open for contributed papers by individuals doing research in the area.

Titles and abstracts of these papers must reach Andrew Schultz, Jr., Upson Hall, Cornell University, Ithaca, New York, by April 15, 1961. The title should include: title of paper, full name and initial of the author, his affiliation and address. The abstract should be carefully prepared to indicate the essence of the paper, the purpose, what was done, and the conclusion; and it should be limited to two hundred words, double spaced, with one carbon.

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The Optimum Allocation of Resources Among the Activities of a Network

by **CHARLES E. CLARK**

System Development Corporation

WE CONSIDER a finite set of activities $a_1, \cdots, a_n$. The set is partially ordered in the sense that for $i \neq j$, either a_i precedes a_j, or a_j precedes a_i, or neither precedes the other; a_i precedes a_j and a_j precedes a_k imply a_i precedes a_k; and no activity precedes itself. An example is represented by the network of Figure 1. The activities are represented by the directed segments $a, \cdots, e$. Activities a and b can commence at any time. However, we assume that they commence at time zero. As soon as b is completed, activities c and e can commence, and we assume that they commence at the completion time of b. After both a and c are completed, d commences. Activity a precedes d, activity b precedes c, d, and e, activity c precedes d, and no activity has either d or e as a predecessor.

An illustrative case is found in (1) which is concerned with the program for the development of the Fleet Ballistic Missile (Polaris). Another application is discussed in (2).

COSTS

To each activity a we must assign a cost c_a. In early sections of this article, this cost can be any positive number, but in later sections the activity costs will be subject to other constraints. The cost c_a is a function $c_a(t_a)$ of the time t_a between the commencement and completion of a. This function, called the cost function, is positive and decreasing. Furthermore $c_a \to \infty$ as $t_a \to 0$, $c_a \to 0$ as $t_a \to \infty$, and the second derivatives $c_a''(t_a)$ is positive for $0 < t_a < \infty$. This implies that the derivative $c_a'(t_a)$ increases continuously and monotonically from $-\infty$ to 0 as t_a increases from 0 to ∞.

EVENTS

Let $a < b$ denote that activity a precedes b. If $a_i < a_j$ and there is no a such that $a_i < a < a_j$, we say that a_i immediately precedes a_j. We shall use "succeeds" to denote the inverse of "precedes."

In Figure 1 the nodes $A, \cdots, D$ are called events. The node A is a special event called the present event. In the network all activities without predecessors emanate from the present event A. The immediate predecessors of c and e are the same; the event B is associated with the completion of all the activities of this set of predecessors (a set with one element b); the time of the event B is the time at which b is completed. Hence, each of c and e could commence at the time of B or later, and we assume that they commence at the time of B. Similarly, the event C is associated with the completion of a and c, and the time of C is the later of the completion times of a and c. We assume that d commences at the time of C.

In general, consider any set of activities $a_1, \cdots, a_p$ which constitute all the immediate predecessors of an activity a. An event is defined which is associated with the completion of all the activities of the set, and the time of the event is the latest among the completion times of the activities of the set. We assume that a commences at the time of this event. In a network representation such as that of Figure 1, the events are represented by the nodes. The event is said to be an immediate successor of $a_1, \cdots, a_p$ and an immediate predecessor of a.

An event A is said to be a predecessor of an event B if there is an activity a with A as immediate predecessor and B as immediate successor. Also, A precedes B by definition if there are activities a and b such that a precedes b, A is an immediate predecessor of a, and b is an immediate predecessor of B.

The term "immediate predecessor" denotes three relations. The term can be applied to an ordered pair of activities, to an activity and event, and to an event and activity. An event can be the immediate predecessor of more than one activity.

To clarify the definition of event, suppose we are modeling a situation in which a is an immediate predecessor of c, and a and b are immediate predecessors of d. It would be incorrect to model this situation as suggested in Figure 2, because Figure 2 indicates incorrectly that c can not start until both a and b are completed. An appropriate model is that of Figure 3. The activity x is an arti-

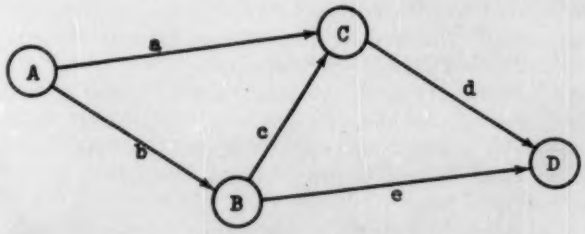

FIGURE 1

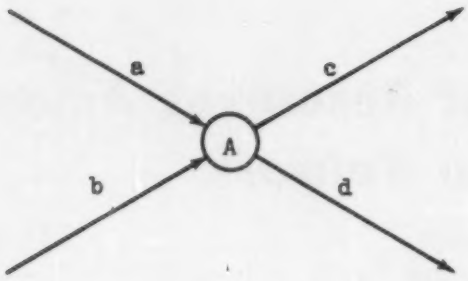

FIGURE 2

ficial activity which requires roughly zero time. More precisely, we would introduce a small number ϵ and an artificial function $c_x(t_x)$ with $c_x(\epsilon) = \epsilon$. The number ϵ might be taken so that $c_a = \epsilon$ indicates one cent and $t_a = \epsilon$ indicates a second.

As a further illustration, suppose that in a real development program an activity a could commence at present, but that it has been decided to commence a one year later than the present. Our model of such a situation would include an artificial activity x with the immediately succeeding event X. The activity x would commence at present, and activity a would be an immediate successor of X. For all cost values between a small and a large amount, the time of x would be close to one year.

There must be at least one activity with no predecessor. To prove this, let us assume the contrary. Let a_1 be any event. Since a_1 has at least one predecessor, we can select a_2 which precedes a_1. Similarly, there is an event a_3 which precedes a_2, and in general an event $a_{(i+1)}$ which precedes a_i, $i = 1, 2, \cdots$. Since the number of events is finite while the sequence a_i is infinite, at least one activity a must occur at least twice in the sequence. This means that a precedes itself, and this is contrary to definition.

We define a special event, called the present event, which is the immediate predecessor of each activity which has no preceding activity. The time of the present event is zero.

In the same way, we define the final event which is the immediate successor of each event which has no succeeding activity. The time of the final event is denoted by T.

SCHEDULES

A schedule consists of the assignment of a cost to each activity. The assumptions concerning the cost functions imply that the time of any activity is determined uniquely by its cost. This implies that the time of each event is uniquely determined by a schedule.

A schedule is also determined if a time is assigned to each activity; the present event being assigned the time zero. The assumptions concerning the cost functions imply that the cost of each activity is uniquely determined by its time.

The partial ordering of the activities induces a partial ordering among the events. Suppose that the event times are assigned any set of values consistent with this partial ordering. A unique schedule is determined in the following way. To each activity we can assign the difference of the times of its immediately succeeding and immediately preceding events. This schedule is called the slackless schedule determined by the event times. However, other schedules can be determined with these same event times. Consider the set of all activities that immediately precede a specific event. All but one of these activities can be reduced in time without disturbing any event time. If at least one such reduction is non-zero for at least one event, the resulting schedule is said to have slack. Hence, if the events are assigned times consistent with the partial ordering of the events, there is a unique slackless schedule with the given event times, and there are infinitely many slack schedules.

THE FUNDAMENTAL PROBLEM

For any schedule there is a total cost C which is the sum of all the activity costs. Furthermore, as stated previously, the time T of the final event is determined by a schedule. Let T_0 be any positive number. The fundamental problem is the determinization of a schedule which is optimum in the sense that it minimizes C subject to the constraint $T = T_0$. This problem will be solved heuristically by means of a mechanical analogue. A formal proof will follow, and a relaxation computational procedure will be described. We say that an activity of a schedule has slack if and only if the activity's time can be increased without a resulting increase in the time of the final event. In an optimum schedule there is no slack. For example, if an optimum schedule exists for the network of Figure 1, the time t_a of a will be the sum of $t_b + t_c$ of the times b and c. Suppose, on the contrary, that the time of a were less than the sum of the times of b and c. The time of event C would be $t_b + t_c$, and a would be completed prior to the time of C. But, in that case, it would be possible to decrease C without changing T simply by increasing the time of a from t_a to $t_b + t_c$. In general, if a schedule is optimum, no activity time can be increased without increasing T; in other words, there is no slack.

However, in some real problems there are constraints

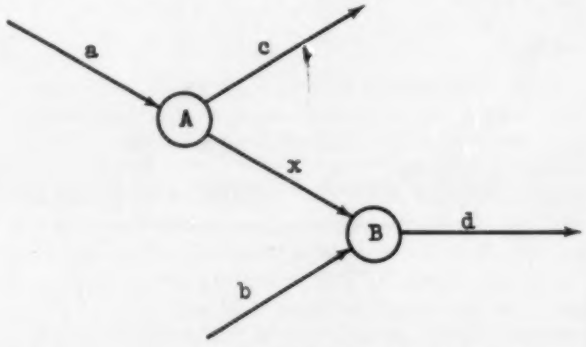

FIGURE 3

on the costs which lead naturally to slack. For example, suppose that Figure 1 represents an optimum schedule. Suppose that an allocation of resources has been committed irrevocably to each activity. In the face of this commitment we wish to reduce the time T of the final event by augmenting the resource allocations. Suppose that it is most economical to reduce the times of both b and d by, say, a month. With these reductions, activity c would be completed a month prior to the time of C as the reader can easily verify. Under the assumptions of the fundamental problem, it would be permissible to increase the time of c by a month. This would reduce the cost of c and, hence, of C. But the denial of cost cut-backs prevents such a saving and leads to an optimum program with slack.

It is possible to handle this illustrative situation by the analysis of the fundamental problem. One simply removes the constraint on the time of activity c, and distorts the cost function $c_c(t_c)$ in the following manner. Let t_0 be the time of activity c in the optimum schedule prior to the resource augmentation. We replace $c_c(t_c)$ by a new cost function. The new cost function equals the old for $t_c \leq t_0$, and the new function decreases by an insignificant amount for a large increment of t_c above t_0. If an optimum schedule for the distorted problem involved a value of t_c greater than t_0, in the application to reality one would assign $t_c = t_0$. For practical purposes, the resulting schedule would be optimum. We shall not present a formal analysis of this matter.

It is sometimes preferable to introduce another analysis for the cases which involve constraints on costs and activity times. This matter is discussed in later sections.

THE FUNDAMENTAL THEOREM: A MECHANICAL ANALOGUE

Consider a schedule. Let t be any time between 0 and the final event time T which is different from all event times. Let $a_1, \cdots, a_j$ be the activities in progress at time t. These are the activities for which the scheduled immediately preceding events have times less than t and the immediately succeeding events have times greater than t. Let τ_i, $i = 1, \cdots, j$, be the schedule time of the activity a_i. Note that t is a clock time, whereas each τ_i is the length of the time interval during which a_i is in progress. We define $D(t)$ to be the sum of the derivatives $c_i'(\tau_i)$, $i = 1, \cdots, j$. If the time of each activity $a_1, \cdots, a_j$ were increased by the infinitesimal amount Δt the cost C would be increased correspondingly by $D(t)\Delta t$ (which is negative when Δt is positive).

The fundamental theorem—there is one and only one optimum schedule; a schedule is optimum if, and only if, it has no slack and $D(t)$ is constant for $0 < t < T$ with t different from all the event times.

Before proving this theorem, we suggest a heuristic derivation based upon a mechanical analogue. As an analogue of the schedule indicated in Figure 1, we introduce the mechanical system of Figure 4. The activities of Figure 1 are replaced by springs, and the events by plates which are free to move to the left or right without rotating; the plate A at $x = 0$ is fixed. To the time of an activity corresponds the length of a spring, and to the cost corresponds the negative of the potential energy. To a time t corresponds the coordinate $x(t)$ indicated in Figure 4, and $x(t) = t$. To $D(t)$ corresponds the sum of the tensions of all springs which have the position $x(t)$ between the coordinates of their end points.

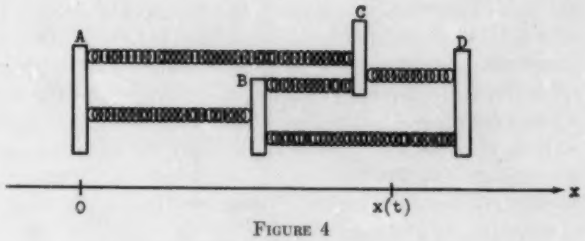

FIGURE 4

Let plate D be held fast at the position $x(T) = T$. The plates B and C will assume equilibrium positions. The formal proof will be analogous to the argument by which one would demonstrate that the equilibrium position is unique, and for this equilibrium position the sum of the tensions in all springs at any position x is constant for $0 < x < T$.

PROOF OF THE FUNDAMENTAL THEOREM

It was proved that an optimum schedule has no slack. The schedules considered are all those without slack.

We shall define a domain of schedules S in an Euclidean space. The partial ordering of the activities induces a partial ordering of the set of all events $A_1, \cdots, A_m$, where A_1 is the present event and A_m is the final event. To simplify notation, we shall use A_i to denote both an event and its time. We interpret $A_1, \cdots, A_m$ as a point in Euclidean m-space. The points that correspond to schedules with $T = T_0$ are the points which satisfy the constraints $A_1 = 0$, $A_m = T_0$, and a set of inequalities $A_i < A_j$ determined by the partial ordering. This domain of the schedules S is a bounded open set in the $(m-2)$ dimensional subspace determined by $A_1 = 0$ and $A_m = T_0$.

Next we shall prove that there is at least one optimum schedule with $T = T_0$. As a point of the domain of schedules S approaches the boundary, at least one difference $A_j - A_i$, constrained to be positive in S, approaches zero. This implies that at least one activity time approaches zero, and hence C becomes infinite. If we consider C defined on the domain of schedules S, and if we define C to be ∞ on the boundary, then C is continuous in $\overline{S}$, the closure of the domain of schedules; of course, we are using the extended notion of continuity which is applicable to functions which can assume the conventional value $+\infty$. Since C is positive, it assumes a minimum in the interior of the domain of schedules. Hence, we have proved that there is at least one optimum schedule with $T = T_0$.

To show that $D(t)$ is constant for an optimum schedule,

we focus attention on a specific optimum schedule. Let t_1 and t_2 be any positive times less than T_0 which are not event times. Suppose $D(t_1)$ is greater than $D(t_2)$. Consider all activities in process at time t_1, in the sense that the activities commence before t_1 and finish after t_1. Let the time of each of these activities be reduced by the infinitesimal amount Δt. Let the times of the activities corresponding to time t_2 be increased by the same amount. The corresponding infinitesimal increase in C is

$$\Delta C = D(t_1)(-\Delta t) + D(t_2)\Delta t$$
$$= [D(t_2) - D(t_1)]\Delta t.$$

Since ΔC is negative, and since the final event time T is unchanged by the compensating time distortions, the schedule prior to the deformation was not optimum. This contradiction proves that for an optimum schedule, $D(t)$ is constant.

The sufficiency of the condition remains to be established. For any schedule optimum or not, $D(t)$ is constant over any time interval which does not contain the time of an event. Consider the finite set of intervals into which the time interval $(0, T)$ is divided by the event times. Since $D(t)$ is constant over each of these intervals, the condition $D(t)$ is constant reduces to a finite set of linear equations among the derivatives of the cost functions. Suppose that there were two essentially different solutions of these linear equations. There would be a linear manifold M of solutions which would contain a boundary point P of the domain of schedules. As this boundary point P is approached by a sequence of points $P_1, P_2, \cdots$ in the intersection of S and M, at least one difference $A_j - A_i$, constrained to be positive in S, approaches zero. Each P_i determines a schedule with event times $A_1^{(i)}, \cdots, A_m^{(i)}$. As P_i approaches P, for each fixed j, $A_j^{(i)}$ approaches a limiting position A_j^{∞}. Let us say that the $A_j^{\infty}, j = 1, \cdots, m$, determine an ideal schedule; the limiting "events" satisfy all the conditions on the events of a schedule except that one or more activity times are zero. Consider a time between 0 and T_0 different from all the ideal event times. For this time t_1 we can compute $D(t_1) = D_{\infty}(t_1)$ for the ideal schedule, and $D_{\infty}(t_1)$ is finite. From continuity as $P_i \to P$, the number $D_i(t_1)$, defined as $D(t_1)$ computed for P_i, has for its limit $D_{\infty}(t_1)$. But for a sufficiently large i, the schedule P_i has an activity with arbitrarily small time and hence arbitrarily large cost. Hence, there is a t_2 for which $|D_i(t_2)|$, computed for P_i, is greater than an arbitrarily large preassigned number. But $D_i(t_1) = D_i(t_2)$ because P_i is in M. This contradiction proves the uniqueness of the cost function derivatives of the schedule with $D(t)$ constant. Since the derivatives determine the costs uniquely, there is only one schedule with $D(t)$ constant. The proof of the fundamental theorem is complete.

NUMERICAL ANALYSIS

To approximate the optimum schedule in a numerical example, the best general procedure we can suggest is the relaxation method illustrated in this section.

For a numerical example, we return to Figure 1. We assume that the relation between the time t and cost c_a of activity A is $c_a = 25/t$. Similarly, for the other activities, we have $c_b = 10/t$, $c_c = 4/t$, $c_d = 2/t$, and $c_e = 1/t$. To complete the problem definition we take $T_0 = 6$.

If $D(t)$ is to have the same value immediately to the right and left of event B, and if the same is to hold with respect to event C, we must have the following relations among the derivatives: $c_c' + c_e' - c_b' = 0$ and $c_d' - c_e' - c_c' = 0$. If x and y are the times of events B and C respectively in the optimum schedule, these relations among the derivatives reduce to

$$f(x, y) = \frac{10}{x^2} - \frac{4}{(y-x)^2} - \frac{1}{(6-x)^2} = 0,$$

$$g(x, y) = \frac{25}{y^2} + \frac{4}{(y-x)^2} - \frac{2}{(6-y)^2} = 0.$$

Furthermore, the cost of the optimum schedule is

$$C(x, y) = \frac{25}{y} + \frac{10}{x} + \frac{4}{y-x} + \frac{2}{6-y} + \frac{1}{6-x}.$$

One can check that $f(3, 5) = g(3, 5) = 0$, and $C(3, 5) = 12\frac{2}{3}$. However, we do not assume that this optimum solution is known, and our task is to approximate it.

We start with the trial values $x = 2$ and $y = 4$. Clearly, our initial approximation to the optimum schedule could be much better than this. Since activities a and b are more costly than d and e, we can be certain that the optimum schedule has x and y greater than 2 and 4 respectively. However, it will be instructive to start with a needlessly crude approximation. In real problems which can involve thousands of activities, it is not easy to obtain a good initial approximation.

We compute the first line of Table 1. Since $f(2, 4) = 1.44$ is positive, the sum of the cost derivatives for activities c and e exceeds the cost derivative for b. Since all derivatives are negative, this means that the absolute value of the cost derivative for b exceeds the sum of the absolute cost derivatives of c and e. Hence, a time change in activity b changes the cost at a greater rate than equal time changes in both c and e. This means that it would be

TABLE 1

Relaxation Computations

x	y	$f(x, y)$	$g(x, y)$	$C(x, y)$
2	4	1.44	2.06	14.500
2	4.8	1.93	.21	13.553
2.9	4.8	−.023	.804	12.751
2.9	4.92	.1048	.2983	12.684
2.9	4.980	.1605	.0102	12.674
2.989	4.980	.0000	.0947	12.667
2.989	4.997	.0170	.0052	12.667
2.998	4.997	.0006	.0142	12.667
		⋮		
3	5	0	0	12.667

profitable to increase the time of b and decrease both the times of c and e by the same amount. This could be accomplished by increasing x to some value greater than 2. However, before doing this we note that $g(2, 4) > f(2, 4)$. Hence, for infinitesimal increments at least, there is more profit in increasing y than x. For the second approximation to the optimum schedule we shall keep $x = 2$ but increase y. As an initial guess of a good value of y we take 5. Since $g(2, 5) = -.56$, and since Table 1 gives $g(2, 4) = 2.06$, linear interpolation gives $g(2, 4.8) = 0$ approximately. Hence the second approximation is $x = 2$, $y = 4.8$. The second row of numbers in Table 1 gives the analysis of this approximation.

Since $f(2, 4.8)$ is positive and numerically larger than $g(2, 4.8)$, the third approximation will be obtained by increasing x. As an initial guess as to an appropriate value for x we take $x = 3$. Since $f(3, 4.8) = -.23$, we interpolate using $f(2, 4.8)$ given in Table 1, and we estimate that $f(2.9, 4.8) = 0$ approximately. This leads to the third row of numbers in Table 1. In this way, Table 1 is constructed except for the last row which corresponds to our *a priori* knowledge of the solution.

CONSTRAINTS ON COST AND TIME

During the remainder of the article we discuss the following problem. A schedule, in general not optimum, is given. The final event has a time greater than T_0. The problem is to determine a schedule which minimizes C subject to the constraints that $T = T_0$ and that no activity has a time greater than its time in the given schedule. In other words, one must determine how a resource augmentation should be made among the activities, it being assumed that no cut-back in an activity's allocation is permitted.

We can not give a complete solution of this second problem other than that indicated above in which artificial, small distortions reduce the new problem to the fundamental problem shown previously. However we shall introduce a new concept, namely, that of a critical path. This concept has been found useful in (1). It leads to good, but not always optimum, solutions of the second problem. In many cases, the critical path analysis produces a good solution after an amount of analysis which is trivial in comparison with the analysis of the fundamental problem. Even if the good solution is inadequate, in many cases it should be determined as an initial approximation for the relaxation analysis of the previous section.

THE CRITICAL PATH

For any schedule the critical path is the set of activities with no slack. In Figure 1, if the time of each activity is 1, the critical path consists of b, c, and d. Indeed, if the times of a and e were increased to any values not exceeding 2, the time of the final event D would not be changed. But if the time of a, b, or c were increased, the time of D would be increased. For an optimum schedule the critical path consists of all activities. However, the critical path may contain only a small fraction of all activities, and it can be a simple succession of activities leading from the present to the final event.

THE EXISTENCE OF THE CRITICAL PATH

The proof that a critical path is not empty is simple. Consider the immediate predecessors of the final event. The final event is the completion time of at least one activity a of this set. If the time of a were increased, the time of the final event would be increased. Hence, the critical path contains at least one activity, namely, a.

It would be easy to prove that the critical path includes a "path" from the present to the final event. Since this fact will not be used, no proof is given.

SLACK AND INFINITESIMAL AUGMENTATIONS

We consider a specific schedule. Consider any activity a and its immediately succeeding event A. Let δ_a be the time of A minus the time at which a terminates. Activity a has slack if $\delta_a > 0$. Let the positive number δ be the smallest of the nonzero numbers δ_a for all activities a. Consider a resource augmentation which is so small that no event time is changed by more than $\delta/3$. After the augmentation, the termination time of a is still less than the time of the immediately succeeding event (by $\delta/3$ or more). Clearly, it would be wasteful to allocate any of the resource augmentation to a.

Slack in an activity may occur in another way. It may be that a terminates at the time of its immediately succeeding event A, but that the activities with A as immediate predecessor can all be delayed. An illustration is obtained by deleting activity c in Figure 1, and by assigning the time 1 to a and d and the time 2 to b and e. The event C will occur at time 1. If the commencement of d is delayed from time 1 to time 3, the final event D is not delayed. This implies that the time of a could be increased 2 units without delay in D. We shall describe this situation by saying that the event C has slack. Clearly, if an event has slack, there is slack in every activity with the event as immediate successor. Again it is clear that it would be wasteful to increase the cost of any activity with this kind of slack, if a resource augmentation is sufficiently small.

These two types of slack are all inclusive. This implies that for sufficiently small resource augmentations, only critical path activities should receive allocations.

DETERMINATION OF THE CRITICAL PATH AND THE EVENT TIMES

When a schedule is given, it is an easy matter to determine the critical path and the time of each event. This is done in (1), and the details will not be repeated.

AN OPTIMUM INFINITESIMAL AUGMENTATION

Next we shall determine an optimum allocation among activities of a resource augmentation which is so small that no allocation should be made to any activity off the

critical path. For each activity a of the critical path, the absolute value of the derivative $c_a'(t_a)$ is calculated at the schedule time t_a. Let us consider first the (nondegenerate) case in which no two of these absolute values are equal, and more generally, no sum of a set of these absolute derivatives is equal to the sum for a different set. The smallest of these numbers corresponds to the activity a_1 for which an infinitesimal reduction in time is cheapest. However, a reduction in the time of this activity may not reduce the time of the final event. An illustration is given by Figure 1 with activity c deleted and with times of a, b, d, and e equal to 1, 2, 4, and 3, respectively. To determine whether a_1 by itself should be reduced in time, we delete activity a_1, and then compute the final event time for the new schedule with one less activity than the original. If the new final event time is less than the original, an infinitesimal reduction in the time of a_1 effects an equal reduction in the final event time. The optimum infinitesimal resource augmentation is one with the complete augmentation allocated to a_1.

Suppose that the new final event time is the same as the old. It is possible that the infinitesimal resource augmentation should be made to a set of activities which include a_1. We delete a_1 from the list of critical path activities, and we add to the list all pairs of critical path activities with a_1 as one member of the pair. For each pair, we compute the sum of the two absolute values of the derivatives. We select the smallest absolute derivative or sum of derivatives from the new list. We must determine whether the infinitesimal resource augmentation should be allocated to this activity or pair of activities. From the given schedule, we delete the activity or the pair of activities. If this deletion reduces the time of the final event, the event or event pair will receive the resource increment. In case of a pair of activities the allocations are made so that the infinitesimal time reductions of the two activities are equal.

This process continues. At each rejection of an activity or set of activities, the list, initially consisting of the critical path activities, is augmented. If $a_1, \cdots, a_k$ is the set of activities rejected, the list is increased by all sets $a_1, \cdots, a_k, a_x$, where x ranges over all indices of critical path activities different from $1, \cdots, k$.

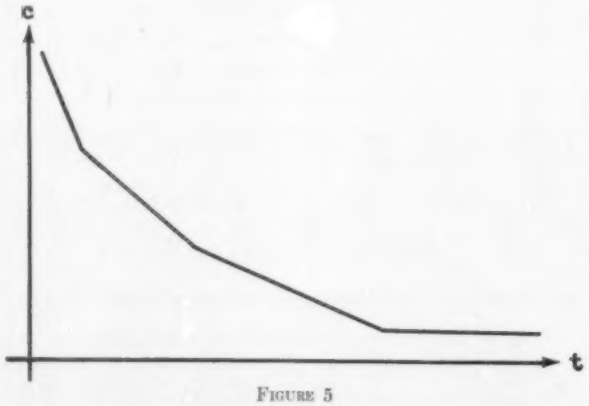

FIGURE 5

We have ignored the possibility of ties among the derivatives or sums of derivatives. In case of ties, one might say that from the point of view of infinitesimals, all sets that are tied are equivalent. However, since the practical application is to small rather than infinitesimal increments, the ties should be resolved by higher derivatives. If the derivatives do not exist, it would be necessary to consider small increments; for each of the alternatives one would calculate the cost of a small time saving.

AN OPTIMUM SMALL RESOURCE AUGMENTATION

We shall show that an optimum infinitesimal resource augmentation determines a small augmentation which is optimum. Consider what happens as the infinitesimal augmentation is steadily increased. There will be a critical value for the augmentation such that further increase in the augmentation will not be optimum. This critical value is determined by one of two possible phenomena. The optimum infinitesimal augmentation involved inequalities among derivatives of the cost functions, and the critical augmentation value may be that value for which the inequalities first fail to hold. As the optimum infinitesimal augmentation steadily increases, let ΔR_1 be the smallest augmentation for which these inequalities fail to hold.

There is a second limitation on the size of the infinitesimal augmentation. As this augmentation is increased, activity times are changed. As some activity times are shortened, previously noncritical activities may become critical. Suppose that the optimum infinitesimal resource allocation is to a set of activities $a_1, \cdots, a_k$. As these activities decrease in time, the final event time decreases. However, there may be a critical resource augmentation ΔR_2 such that as the augmentation increases beyond ΔR_2, there is no corresponding reduction in the final event time. If no such limitation exists, we take $\Delta R_2 = +\infty$.

Let ΔR be the smaller of ΔR_1 and ΔR_2. An optimum small resource augmentation is obtained by extending the optimum infinitesimal augmentation until the total cost increase is ΔR.

The calculation of ΔR_2 is easy. One deletes $a_1, \cdots, a_k$ from the given schedule, and computes the corresponding reduction in the final event time. Each of $a_1, \cdots, a_k$ is reduced in time by the final event time reduction. The sum of the corresponding cost increments is ΔR_2.

The only difficult computation considered in the present section is that of ΔR_1. For this computation, one must determine the second best infinitesimal augmentation (in case of ties, the best other than the augmentations that are tied). This is easy. But, as the optimum infinitesimal augmentation is effected and steadily increased, one must determine when the absolute derivative sum for the optimum infinitesimal augmentation becomes equal to the absolute derivative sum for the second best augmentation. In general, this must be determined by interpola-

tion among trial values of the augmentation.

However, this difficulty is much less in the following situation. Suppose that the graphs of the cost functions are made up of straight line segments such as in Figure 5. The derivatives would change in value only at isolated times. The critical value ΔR_1 would correspond to one of the corners of the graphs of the cost functions $a_1, \cdots, a_k$.

In solving the fundamental problem, one would distort the graph of Figure 5 into a graph with a continuously turning tangent. But such a distortion would not be made in the present analysis.

THE INTEGRATION OF OPTIMUM SMALL AUGMENTATIONS

Suppose that the final event time T of a schedule is reduced to T_1 by one optimum resource augmentation, and from T_1 to T_2 by a second augmentation which is optimum with respect to the schedule with final event time T_1 (the second augmentation may not be optimum for the schedule with final event time T). Unfortunately, the combination of these two allocations is not always an optimum augmentation. This is demonstrated by the following illustration.

Suppose that Figure 1 is a schedule without slack. Suppose that each of a, c, and e can be reduced one month at a cost of 1 each, each of b and d can be reduced one month at a cost of 10 each, and that any other time reduction would incur a huge cost. The reader must excuse our violation of the continuity conditions. This violation should not diminish the force of the counter example. If the time of D were to be reduced one month, the optimum allocation would be 1 to each of a, c and e. After this were done, if the time of D were to be reduced a second month by a further allocation, the optimum allocation would be 10 to each of b and d. As a result, the time of D is reduced 2 months at a cost of 23. But this same reduction in the time of D can be achieved at a cost of 22; the optimum allocation is 1 to each of a and e and 10 to each of b and d.

However, we can determine a succession of optimum small augmentations, continuing the sequence of steps until the sum of the ΔR's exhaust a given resource allocation, or until a given reduction in the final event time is achieved. In many situations, the combined augmentation, though not optimum, will be better than augmentations determined by procedures other than that of the first eight sections of this article.

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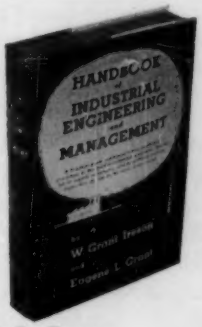

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Managerial Economics and Industrial Engineering

by **ALAN J. LEVY**

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THE PROFESSION of Industrial Engineering has made an important contribution to industry by developing and applying a group of principles, techniques and practices to provide meaningful solutions to problems in cost analysis, profit measurement, cost control and capital management. These were the answers that came from engineering economics, break-even analysis and budgeting. Today, an enlarged approach to the problem of the economics of the firm has developed into a body of writing and a group of practices generally called Managerial Economics. This article outlines the approach and substance of Managerial Economics, compares the techniques with the established practices of Industrial Engineering, considers the relationship of Managerial Economics to other professions, discusses inclusion of Managerial Economic material in Industrial Engineering graduate work and presents the opportunities Managerial Economic analysis offers to Industrial Engineering.

BACKGROUND

In the last ten years, major steps have been taken to convert economic price theory into practical business economics for solving management problems and formulating policies. Price theory, particularly the area called the theory of the firm, has become a great intellectual edifice filled with elegant analysis that either contained sets of assumptions that were too simple, or too complicated to be managerially useful. Managerial Economics is a departure from this theoretical apparatus; it recognizes the underlying theory and logic of economic thought but develops techniques that may be directly applied for specific answers or as guides to practical decision-making in the complex industrial world.

Instead of the classic economic view that the entrepreneur is a passive factor pushed by marked forces, Managerial Economics takes the view that management can do something to change costs and demand and that economic analysis gives management useful and practical tools to analyze business situations.

The subject matter of Managerial Economics includes: the economics of production management, cost analysis and cost measurement, product line analysis and product line strategy, profit and profit measurement, pricing practices and policies, competition and the competitive environment, capital management and capital budgeting and the economic effects of government, institutions and world condition upon business.

These are and are not areas in which Industrial Engineering now works; and a few of them are and are not areas covered in standard Industrial Engineering handbooks or academic programs; these are the border line areas that run Industrial Engineering into other professions. Before making a more detailed exposition of Managerial Economics, a short description of Price Theory will be presented to provide the background to compare the power analysis and technique.

PRICE THEORY

The area of economics known as Price Theory is concerned with explaining market prices for commodities that result from the twin effect of supply and demand (7). Underlying the description of these two market forces is the technique of marginal analysis and a whole array of differential equations, geometric diagrams, elasticities, and assumptions about time periods. In addition, price theory literature concentrates on concepts of profit maximization, the law of diminishing returns, economies of scale, external economies, internal economies and the market structure of competitive or restricted markets. These analytic tools have been built to explain transactions in the market place, how specific prices are finally established and how a business firm operates and reacts to the forces in the economy. Price theory solutions are generalizations within a given set of fixed assumptions.

MANAGERIAL ECONOMICS

Managerial Economics thought assumes a reasonable familiarity with these concepts but is not interested in theoretical generalization; Managerial Economics is concerned with techniques to answer specific industrial and business problems. Wedded to the background of Price Theory, the Managerial Economic practitioners have made extensive use of correlation analysis, the major tool used in Econometric forecasting. Explicit and implicit in this work is the assumption that management can predict trends and take action to adjust their operation. Ex-

plicit and implicit in the work are a group of techniques that can be used to measure the effect of changes in operation.

But beyond the quantitative techniques that grind out mechanical answers, Managerial Economics also gives a qualitative evaluation of situations and sharpens management's areas of decision in complex interrelated problems where no equation can contain all the parameters. Since most management decisions ultimately depend on judgment, managerial economic analysis and classification narrows the area of decision-making, and thus offers the possibility of improved decisions. While Managerial Economics gives technical answers in market analysis and capital budgeting problems, the use of these results is essentially a decision based on judgment. Managerial Economic analysis, with its background of technical economics gives the general picture of the enterprise as a whole, and the enterprise's role in the market; thus relating the technical answers derived from quantitative analysis in specific areas with the firm's position in the economy. There are no equations designed for analyzing the enterprise as a whole; managements answers are answers of judgment sharpened by meaningful analysis. For example, price theory analysis assumes management policies have but one main end, profit maximization. Today it is clearly recognized that profit maximization is not the major goal in modern business; management is more interested in sales volume, growth, security, market share and diversity of products; not maximum profits (1). Managerial economic analysis directly attacks the problem by stating the real goals of business and then enables management to establish programs that produce the best possible results within the limits of the stated goals and the limitations of the market.

Following, in outline form, are the major subjects of Managerial Economics.

COST

Industrial Engineering was developed in the factory and was initially concerned with the major problem of production: least cost. The Industrial Engineer was not only reducing cost by method changes, improved layouts and revised work crews, but he brought into the factory the engineering oriented cost collecting and cost analyzing systems that are used by management today.

There are essentially three different approaches that may be used in analyzing cost (6). There is the accounting procedure of classifying all costs into various categories (fixed, variable and semi-variable) and analyzing the proportions of costs in each area and calculating the variation in costs at different levels of output. There is the engineering procedure that studies the physical relationship (rated capacity, gallons of inputs, etc.) and converts these relationships into dollars to arrive at estimated costs. There is the Managerial Economic procedure that uses an econometric or statistical method to construct cost curves or functions that show the variations in cost generated by changes in output and then intreprets these curves using economic theory.

The three procedures in cost measurement should not be considered competitive; the practicing Industrial Engineer has regularly used both the accounting and engineering method, depending upon the particular situation. The econometric procedure adds a new dimension to an old problem by bringing to bear, on specific problems, economic analysis that offers the possibility of obtaining new insight into business costs and more useful solutions to business problems.

Managerial Economic literature has thrown another light onto the problem of cost by developing and analyzing more categories of cost than generally found in Industrial Engineering or accounting literature. Spencer and Siegelman (6) detail the following ten different sets of classification that can be used in approaching a specific cost problem:

1. Absolute Costs and Alternative Costs.
2. Direct and Indirect Costs.
3. Fixed Cost and Variable Cost.
4. Short-Run and Long-Run Costs.
5. Differential (Incremental) Costs and Residual Costs.
6. Sunk, Shutdown and Abandonment Costs.
7. Urgent and Postponable Costs.
8. Escapable and Inescapable Costs.
9. Controllable and Uncontrollable Costs.
10. Replacement Cost and Original Cost.

To obtain managerial useful information, the cost problem that must be solved must be clearly stated in order to provide the framework for meaningful conclusions. Establishing costs are conceptually and practically very difficult; therefore, a clear classification of the problem and the relationship of specific cost to the company, as a whole, is an improvement in obtaining useful managerial solutions.

PRODUCTION MANAGEMENT

Managerial Economic analysis makes two contributions in the area of production management; it establishes the production function and develops product-line policies. Where applicable, the econometric and Operations Research tools of correlation analysis are introduced to establish relationships between the physical inputs and outputs of industrial processes; that is the production function itself is formulated. When the physical relationships between the productive services and the output are established, the firm's cost structure can be derived. This analysis helps both in making decisions about the production process and in establishing a basis for econometric cost analysis.

The economic analysis of product line policy is an area where the full value of economic thought is brought to management. This analysis is not of the internal relationship but considers the effect on the firm's product lines that result from changes in style and taste, secular or

seasonal shifts in demand, changes in methods of distribution and competitive action. Managerial Economic analysis comes to grips with the problem of excess capacity, additions to the product line, eliminating existing products, vertical and horizontal integration and subcontracting portions of the product line. The product line strategy is a major management problem and sound economic analysis can help when formulating decisions in this area.

PROFITS

Profit is the final acid test as to the success or failure of management's planning and control. But profits as stated on year-end accounting Profit and Loss statements, and actual profit as measured by an economist, usually are two very different figures and concepts (2). An understanding of the difference will greatly help management make decisions. Managerial Economic analysis of profit initially concerns itself with technical measurement such as converting mixed dollars into constant dollars or contemporary dollars; converting book inventory figures to real inventory figures devoid of inflationary or deflationary effects resulting from accounting procedures; revising the depreciation schedule, making allowances for windfall profits and using the concept of opportunity cost in evaluating results of the operation.

Beside the technical adjustments, there are major analytic problems to grapple with in evaluating a particular firm's profit. Classic economics had developed the concept of profit maximization; as though management's primary goal was to maximize profit. But in the complex modern world, profit maximization is rarely, if ever, the major goal. Extensive studies and writings in economic and managerial economic literature establish that the goals of modern managers are maximizing sales volume, increasing bureaucratic security, enlarging market shares, diversifying product line, or enlarging the prestige of the chief executive. William Baumol (1) states that the sales maximizing efforts of modern American management are the major growth factor in our economy. Growth is a more valuable result than the short term profit maximizing objectives of simplified economics. Confrontation with the Managerial Economic analysis of profit gives management a realistic basis on which to plan and act.

DEMAND ANALYSIS

Economics is concerned with both supply and demand; both the costs that contribute to the value of a commodity and the desires and needs that give value to a product. The measurement of demand, the forecasting of the market and the trends in an industry are all problems in the area of marketing. While the Industrial Engineer has concerned himself with production or efficiency, a completely separate profession, Marketing and Market Analysis, has developed to establish the sales budget and market forecast. Basic to market analysis is economic thought and analysis in establishing trends, measuring changes in demand, projecting trends or using econometric correlation analysis to relate an industry's sales with major trends in the economy. Although market analysis is not a province of Industrial Engineering, a better understanding of market analysis would improve the Industrial Engineer's effectiveness when studying the product line, analyzing the capacity of a plant, planning a new plant, or studying the productive facilities.

One difficult area of demand, the cost of advertising, has been studied in detail by economists. Measuring advertising costs and comparing them against revenue is often an [illegible] that is never properly carried out in business. Managerial Economics has shed light on the cost of marketing problem and aids in the understanding and control of these costs.

CAPITAL MANAGEMENT

In the area of capital management both engineering economics and Managerial Economic analysis and practices are essentially the same—the two literatures are enriching each other. Both study problems in the relative worths of alternative investments, replacement policy, economic lot size and methods of solution that use compound interest calculation, statistical theory and game theory. Great emphasis is placed on the uncertainty in formulating capital decision (5).

Managerial Economic literature goes one step further than the typical engineering analysis; it covers the problem of raising the needed capital from internal sources, i.e., the use of retained earnings, or raising money from external sources, either the banking community or public financing.

PRICING AND COMPETITION

The final management problem is to establish prices for the firm's products and to establish these prices within the competitive environment in which the firm operates. The American economy is a price orientated and price directed economy, but exactly how prices are set and changed depends on the market structure of the industry and the goals of management. The theory of the firm is designed to explain how the business unit conducts its activity for profit and managerial economic literature has adapted and expanded on the various competitive models and pricing policies (3). The major emphasis in this analysis is the examination of imperfect competition, monopolistic competition and oligopoly with the greatest emphasis on oligopoly.

The pricing policies and practices of multi-product corporation are both conceptually and practically very difficult problems. Reports on how business firms actually formulate price policies, besides acting as a price follower, have been documented in a number of studies. Kaplan's study (4) shows that firms have various policies such as a target return on investment, price stabilization, maintenance or improvement of their market share, leadership

and followership and policies and prices for product differentiation. In the area of price there are no rigid formulas but economic studies and analysis give management the necessary guides for setting prices in an imperfect market.

MANAGERIAL ECONOMICS AND INDUSTRIAL ENGINEERING

Operations Research techniques brought mathematical statisticians, physical scientists, communication engineers and others into solving business problems. Managerial Economics is now introducing many economists into the active business world. Managerial Economics has also given the business school graduate a fine kit of tools in which he can vastly improve the quality of his professional help to business. It is the author's opinion that just as Industrial Engineering absorbs and uses most of the advances in Operations Research, Industrial Engineering must also absorb most of the developments in Managerial Economics because they so actively complement and advance Industrial Engineering activity. In addition, the author believes Industrial Engineering is the profession best equipped to incorporate Managerial Economic analysis in its everyday work.

There are a variety of professions today that actively provide the analysis, recommendations and solutions management uses in running businesses, organizations and institutions. As society advances and the economy becomes more complex, the variety of problems to be solved becomes greater and the level of the solution becomes higher. Management problems have become more difficult and management needs more help from Industrial Engineers, administrators, lawyers, accountants, market analysts, advertising executives, not to mention public relations, and whole new galaxies of specialized professions. These professions all help in giving technical solutions to some of the problems management must solve. These professions are also the major source of management. Management runs business, companies or institutions and the central problem of management is making effective use of the factors of production and judging the market. The essential capacity of management is to make decisions; the ability to decide on a course of action. The major skill of management is to control operations. It is in these areas that Managerial Economics can enlarge the capacities of Industrial Engineers and the service that they bring to industry.

The preceding outline of the major areas of Managerial Economics highlights where the ideas and the methodology of Managerial Economics may be used to supplement and improve Industrial Engineering work. While Industrial Engineers will not be the only ones to apply these ideas they are the best equipped to effectively use this material. It should be clearly recognized that there is a great overlapping of work in the professions that serve management, and there is an endless defining and redefining of the areas of responsibility and service of each of the professions to business. The other professions will also use these ideas and Managerial Economics has created the new profession of the Business Economists.[1]

The Industrial Engineer's primary advantage in using this material is that he is a technical man with an engineering background enabling him to command the technology of the enterprise and he also possesses the economic-cost background that Industrial Engineers have been developing and using for a long time. Industrial Engineers are ideally equipped to make econometric analysis, because they are strong in statistical mathematics and are already, in fact, doing these studies. In addition, Industrial Engineers are management orientated so that they are control conscious and are ready to measure the effectiveness of this work.

Business Economists will use Managerial Economics as their major tool. They developed the techniques and are publishing most of the work appearing in periodicals. When they receive the right help in mastering the technology of the business, they are in a position to make the most penetrating economic analysis. But the business economist is not equipped to move into the line of action in changing methods or other factors of production since his background in the technical area is limited. The business economist can usually expand his work into the market area; particularly in market forecasting—the area where he has performed most of his work. The number of firms using business economists are relatively few, primarily larger corporations. Industrial Engineers work in all size firms and they will be able to bring these techniques to medium and small companies or organizations that do not hire the great spectrum of specialists found in the major corporations.

Controllers will use some of the cost concepts and capital management techniques of Managerial Economics but they will not be able to go as far with these techniques as will Industrial Engineers. Accountants as such will do very little with these concepts though the management control departments of the larger Certified Public Accountant firms will have personnel who can handle Managerial Economic thought and will use these techniques.

INCLUSION IN INDUSTRIAL ENGINEERING CURRICULUM

A course in Managerial Economics should be included in all graduate programs of Industrial Engineering. While some of the material is already incorporated in the elementary engineering economic courses, a suitable treatment of this field requires a full graduate course. Students should have completed at least a year of college economics, a year of statistical mathematics and a course in accounting. The economic background should be strong in price theory, although the typical one year college

[1] The National Association of Business Economists, P. O. Box 6878, Philadelphia 32, Pennsylvania. Founded in 1959, it now has 425 members.

course usually gives little time to price theory. Introductory economic courses tend to concentrate on income theory and fiscal policy and banking theory and monetary policy. These are essentials in preparation for citizenship but do not give the detailed background needed to study the economics of the firm. In schools that have departments of Industrial Engineering, effort should be made to enlarge the price theory sections of introductory economic courses or else the Industrial Engineering Department should run its own program. Many business schools already have full year courses in Managerial Economics, and Industrial Engineering schools are beginning to incorporate them into graduate programs. These courses are directly listed as "Managerial Economics" or as at Stevens, called "Economics of the Firm," or as at New York University called, "Economics of Business Policy."

A course in Managerial Economics will also introduce the Industrial Engineering student to several topics he does not now receive in school; demand and market analysis and pricing and competitive market structure. These are essential areas of management and since Industrial Engineers are one of the most logical and typical sources of managerial material, an awareness and background in the demand side of the market should make the Industrial Engineer's potential as management material stronger than it is today.

CONCLUSION

The important applications of economic theory and managerial economic thought in the formulation of business policies and plans were reviewed in this article. The subject matter of Managerial Economics is sufficient to establish a new profession, the business economist. Yet major areas of Managerial Economic analysis complement or add to the work of Industrial Engineering. Since Engineering is an applied science and art, it behooves the profession of Industrial Engineering to adapt the results of this economic science and use the material to improve the service our profession renders industry.

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The Aircraft Progress Curve—Modified for Design Changes

by **ANAND GARG** *and* **PIERCE MILLIMAN**

Technical Staff, Transport Division, Boeing Airplane Company

THE PROGRESS curve formula now extensively used in the aircraft industry for estimating labor requirements does not allow for the effect of product design changes. The formula has been modified to include this factor. Significant improvements in man-hour estimates for the Boeing 707 family were achieved through the use of the modified formula.

The development of the modified formula and a procedure for practical calculations are presented in this article.

SOME BACKGROUND ON PROGRESS CURVES

There are many reasons why a manufacturer may wish to estimate the improvement rate of a labor force performing a large scale repetitive production function. Among these is the need to do contract estimating and production planning and control.

The technique now widely used for this purpose in the aircraft industry had its beginning in a formula developed by T. P. Wright in 1936 (2) (3).

$$\overline{Y} = ax^n \qquad \text{Eq. 1.}$$

where $\overline{Y}$ is the estimated average direct man-hours per unit for the first x units, and a and $n (n<0)$ are parametric constants. a also represents the direct man-hours required for the first unit.

The most commonly used contemporary estimating formula is

$$Y = a(x+b)^n \qquad \text{Eq. 2.}$$

and is usually referred to as the "Stanford-b formula" or the "learning formula with a b-factor" (1).

In the foregoing formula, Y is direct man-hours required for cumulative unit number x; a, b, and n are parametric constants and are usually estimated through a combination of judgment and experience.

The parameter b represents the equivalent-units of experience available at the start of a manufacturing program. Generally, b lies between 1 and 10, 4 being a typical value. For the case $b=0$, a represents man-hours for the first unit. The parameter n is negative and usually is greater than -1. ($-.5$ is a typical value.)

A typical progress curve of the Stanford-b type is exhibited in Figure 1. The curve is asymptotic to a straight line with slope n, and approaches such a line over its entire length as b approaches zero.

Such a curve has satisfactorily described the general features of many large scale military aircraft production programs, including the Boeing B-17, B-47 and B-52 programs. It does not, however, follow the actual points of a particular program in detail.

A DEFICIENCY OF THE CURRENT FORMULATION

One feature of a program which would be expected to introduce deviations from the theoretical Stanford-b curve is design differences between different airplanes of the same program. This has been particularly marked in the Boeing 707 commercial jet transport series. The actual direct man-hour curve for Boeing 707's is of the type shown in Figure 2.

Each break in the actual data from a smooth trend line corresponds to the production of an airplane for a new customer. In part, the first unit for a customer is a unique airplane. The differences over preceding units correspond to special customer requirements, e.g., custom interiors. This led to an attempt to modify the progress curve to include the effect of product design changes.

DEVELOPMENT OF THE MODIFIED PROGRESS CURVE

It will be recognized that some portions of the work of building an airplane will be identical for all airplanes.

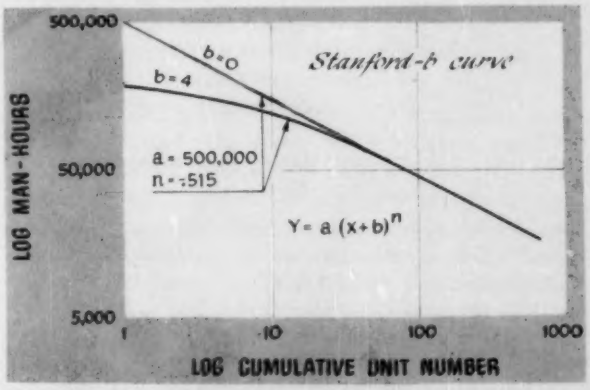

FIGURE 1

FIGURE 2

Other portions will be the same for some, but not for all airplanes, and so on.

At an arbitrary point in a production program, basic portions will tend to be accomplished more efficiently than others, because of a larger number of units of prior experience.

Consider the case of two variations of a basic airplane. Figure 3 illustrates the overlap of work between the two versions, A and B.

In manufacturing the airplanes, three work groups are encountered:

1. Work common to A and B
2. Work unique to A
3. Work unique to B

Each work group is characterized by the presence or absence of each of the versions. Let symbol A denote the presence of version A in a work group, and symbol $\overline{A}$ denote the absence of version A. The three work groups can then be represented as follows:

1. Work common to A and B —AB
2. Work unique to A —$A\overline{B}$
3. Work unique to B —$\overline{A}B$

The work on an airplane of type A is the sum of work components AB and $A\overline{B}$, while the work on an airplane of type B is the sum of work components AB and $\overline{A}B$.

Let Y_{AB}, $Y_{A\overline{B}}$, $Y_{\overline{A}B}$ = man-hours required for the elements of work in categories AB, $A\overline{B}$ and $\overline{A}B$, respectively.

Y_A, Y_B = total man-hours required for airplane type A and B, respectively.

x_A = cumulative unit number, airplane type A.

x_B = cumulative unit number, airplane type B.

The man-hours required to manufacture an airplane of type B will be equal to the sum of man-hours required for work components AB and $\overline{A}B$.

$$Y_B = Y_{AB} + Y_{\overline{A}B} \qquad \text{Eq. 3.}$$

Similarly,

$$Y_A = Y_{AB} + Y_{A\overline{B}} \qquad \text{Eq. 4.}$$

Using Eq. 2., we get

$$Y_{AB} = a_{AB}(x_{AB} + b_{AB})^{n_{AB}} \qquad \text{Eq. 5.}$$

$$Y_{\overline{A}B} = a_{\overline{A}B}(x_{\overline{A}B} + b_{\overline{A}B})^{n_{\overline{A}B}} \qquad \text{Eq. 6.}$$

$$Y_{A\overline{B}} = a_{A\overline{B}}(x_{A\overline{B}} + b_{A\overline{B}})^{n_{A\overline{B}}} \qquad \text{Eq. 7.}$$

where

$$x_{AB} = x_A + x_B$$
$$x_{\overline{A}B} = 0 + x_B$$
$$x_{A\overline{B}} = x_A + 0$$

As the number of versions increases, the number of work components grows. Consider, for example, three versions of an airplane. The overlap of work is diagrammed in Figure 4.

Consider the problem of estimating manufacturing man-hours for version B, unit number x_B. This is the sum of work components $\overline{A}B\overline{C}$, $AB\overline{C}$, $\overline{A}BC$, and ABC. Using the notation introduced earlier, we have

$$Y_B = Y_{\overline{A}B\overline{C}} + Y_{AB\overline{C}} + Y_{\overline{A}BC} + Y_{ABC} \qquad \text{Eq. 8.}$$

and

$$Y_{\overline{A}B\overline{C}} = a_{\overline{A}B\overline{C}}(x_{\overline{A}B\overline{C}} + b_{\overline{A}B\overline{C}})^{n_{\overline{A}B\overline{C}}} \qquad \text{Eq. 9.}$$

$$Y_{AB\overline{C}} = a_{AB\overline{C}}(x_{AB\overline{C}} + b_{ABC})^{n_{AB\overline{C}}} \qquad \text{Eq. 10.}$$

$$Y_{\overline{A}BC} = a_{\overline{A}BC}(x_{\overline{A}BC} + b_{\overline{A}BC})^{n_{\overline{A}BC}} \qquad \text{Eq. 11.}$$

$$Y_{ABC} = a_{ABC}(x_{ABC} + b_{ABC})^{n_{ABC}} \qquad \text{Eq. 12.}$$

where

$$x_{\overline{A}B\overline{C}} = 0 + x_B + 0$$
$$x_{AB\overline{C}} = x_A + x_B + 0$$
$$x_{\overline{A}BC} = 0 + x_B + x_C$$
$$x_{ABC} = x_A + x_B + x_C$$

and other terms are parametric constants. Similar expressions can be written for other airplanes.

EXTENSION TO N VERSIONS

The foregoing idea can be extended to N versions of an airplane. If each of the work groups ($A\overline{BCD}\cdots$, $AB\overline{CD}\cdots$, $\cdots$, $ABCD\cdots$) is assigned a unique

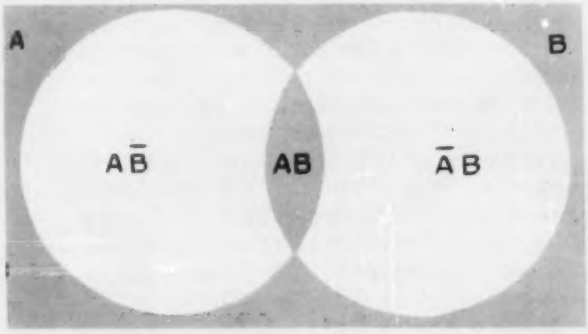

FIGURE 3

number, i.e., 1, 2, · · · , i, · · · , the estimating formula can be written as

$$Y_j = \sum_{i=1}^{2^N-1} a_i \delta_i^j (x_i + b_i)^{n_i} \qquad \text{Eq. 13.}$$

where $\delta_i^j = 0$ for work groups which do not contain the jth version, and $\delta_i^j = 1$ otherwise.

The total number of experience groups is $2^N - 1$, where N is the number of versions in the airplane family. For any particular airplane, however, only 2^{N-1} work groups would be pertinent.

It is important to note that x_i, designating the number of units of experience for work category i, is independent of the sequence in which the earlier units were produced.

FIXING PARAMETER VALUES IN THE MODIFIED PROGRESS FORMULA

Before Eq. 13. can be employed, the parameters a_i, b_i, and n_i must be determined. While, theoretically, each of them might be expected to vary with airplane version, practical considerations dictate that some simplifying assumptions be made before using Eq. 13.

The parameters b_i and n_i might be expected to be constant for one family of airplanes and this was assumed for the Boeing 707 program, on which the modified progress curve was tested. The parameter a_i, on the other hand, will depend on the amount of work present in a work group.

One measure of a job's size is the number of engineering drawings associated with it, D_i. It was conjectured that

$$a_i = kD_i \qquad \text{Eq. 14.}$$

Two hypotheses about k were suggested:

1. k is chosen so that a unit of any version would require a fixed number of man-hours, Y_f, if it were the first airplane in the program. Thus,

$$Y_A = Y_B = \cdots = \sum_{i=1}^{2^N-1} a_i \delta_i^j (1 + b)^n = Y_f \qquad \text{Eq. 15.}$$

2. k is chosen so that a unit of any version built as the first unit in a program would require man-hours directly proportional to the total number of drawings associated with the version. This will lead to different unit 1 man-hour requirements for different versions, unless the total number of drawings is the same for all versions.

For the Boeing 707 family, hypothesis 1 appeared the more reasonable of the two, and was chosen.

When Eq. 14. and Eq. 15. are combined, it is seen that hypothesis 1 implies

$$Y_f = k(1 + b)^n \sum_{i=1}^{2^N-1} \delta_i^j D_i \qquad \text{Eq. 16.}$$

where D_i is the number of drawings for the ith work group. Therefore,

$$Y_f = k(1 + b)^n D^j \qquad \text{Eq. 17.}$$

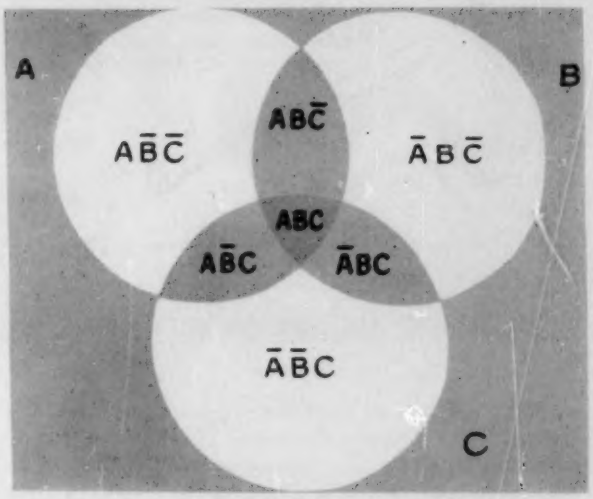

FIGURE 4

where D^j is the total number of drawings for the jth version.

Since the total number of drawings may vary with version, k will take different values for different versions. From Eq. 17., one obtains

$$k^j = \frac{Y_f}{(1 + b)^n D^j} \qquad \text{Eq. 18.}$$

k has been superscripted to show its dependence on version.

If Eq. 13., Eq. 14. and Eq. 18. are combined, we get

$$Y_j = k^j \sum_{i=1}^{2^N-1} \delta_i^j D_i (x_i + b)^n \qquad \text{Eq. 19.}$$

$$Y_j = \frac{Y_f}{(1 + b)^n D^j} \sum_{i=1}^{2^N-1} \delta_i^j D_i (x_i + b)^n \qquad \text{Eq. 20.}$$

The parameters Y_f, b and n may be estimated from actual experience, if a program is in progress. Otherwise, they can be selected by methods ordinarily used to estimate parameters in the Stanford-b formula (1). Then, the effect of introducing design changes can be evaluated with Eq. 20.

TEST RESULTS FROM THE BOEING 707 FAMILY OF AIRPLANES

The mathematical model developed (modified progress curve) was tested on assembly shop direct man-hours for the first forty-six 707-120 series, and three 707-320 series Boeing airplanes. Eleven different versions were involved with the Boeing 707 family being considered as a modification of the Boeing KC-135 jet tanker.

Direct man-hours for 707-120 unit 1 was known and the values of b and n were estimated from actual man-hour data for the first five 707-120 airplanes. Drawing commonness among the airplanes was determined from a ten per cent stratified random sample of drawings. To

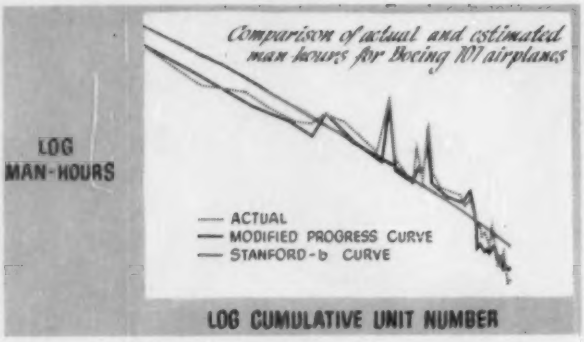
Comparison of actual and estimated man-hours for Boeing 707 airplanes
LOG MAN-HOURS
— ACTUAL
— MODIFIED PROGRESS CURVE
— STANFORD-b CURVE
LOG CUMULATIVE UNIT NUMBER

FIGURE 5

simplify calculations, combinations were restricted to a maximum of five airplane versions. Therefore, some combinations pertaining to small segments of the total jobs were neglected, with little effect on the results. A comparison of actual man-hours, estimated man-hours based on Eq. 2., and estimated man-hours based on Eq. 20., is shown in Figure 5. The deviations of the two estimates from actual data are shown in Table 1 and Figure 6. The use of the modified progress curve resulted in much better estimates than those obtained by using the Stanford-*b* curve.

A HYPOTHETICAL EXAMPLE

A hypothetical example is presented to illustrate the computational procedure outlined previously.

Data: Three versions, *A*, *B* and *C*, of an airplane are scheduled to be built.

Cumulative Unit No.	*Airplane Version*
1	*A*
2	*A*
3	*B*
4	*B*
5	*C*
6	*C*
7	*A*
8	*B*
9	*C*

An analysis of engineering drawings shows:

Group No.	Group	No. of Drawings in the Group
1	$A\overline{B}\overline{C}$	5,000
2	$AB\overline{C}$	3,000
3	$A\overline{B}C$	3,000
4	ABC	7,000
5	$\overline{A}B\overline{C}$	4,000
6	$\overline{A}BC$	6,000
7	$\overline{A}\overline{B}C$	5,000

It has been estimated that

$$Y_f = 200{,}000 \text{ man-hours}$$
$$b = 4.00$$
$$n = -.500$$

The assumptions leading to Eq. 20. are taken to be valid. Man-hour estimates for each of the nine airplanes are required.

COMPUTATIONS

Airplane Version A (Cumulative unit numbers 1, 2 and 7)

Estimates for the first two airplanes can be made directly. For unit 1,

$$Y_A = 200{,}000 = a(1+4)^{-.500}$$
$$a = \frac{200{,}000}{5^{-.500}} = 447{,}000$$

For unit 2,

$$Y_A = 447{,}000(2+4)^{-.500} = 182{,}000$$

For unit 7,

$$x_A = 3, \qquad x_B = 2, \qquad x_C = 2$$

$$D^A = \sum_{i=1}^{7} D_i\delta_i^A = 5{,}000 + 3{,}000 + 3{,}000 + 7{,}000 = 18{,}000,$$

since

$$\delta_5^A = \delta_6^A = \delta_7^A = 0.$$

$$k^A = \frac{Y_f}{D^A(1+b)^n} = \frac{200{,}000}{18{,}000(1+4)^{-.500}} = 24.8$$

Using Eq. 20.,

$$Y_A = k^A \sum_{i=1}^{7} D_i\delta_i^A(x_i+b)^n$$
$$= 24.8[5{,}000(7)^{-.500} + 3{,}000(9)^{-.500} + 3{,}000(9)^{-.500} + 7{,}000(11)^{-.500}]$$
$$= 149{,}000$$

Airplane Version B (Cumulative unit numbers 3, 4 and 8)

For units 3 and 4, only the overlap of work between *A* and *B* need be considered. (*C* will be considered only after four units are completed.) The relevant work groups for units 3 and 4 are:

1. $\overline{A}B = \overline{A}B\overline{C} + \overline{A}BC$
2. $AB = AB\overline{C} + ABC$

TABLE 1

Error Per Cent*	Per Cent of Airplanes With Estimates Within the Indicated Error	
	Basis of Estimate	
	Modified Progress Curve	Stanford-*b* Curve
5	48	18
10	86	48
15	92	74
20	96	80
30	98	90
40	100	94
100	100	100

* Note:

$$\text{Error per cent} = \frac{(\text{Actual man-hours} - \text{estimated man-hours})100}{\text{Actual man-hours}}.$$

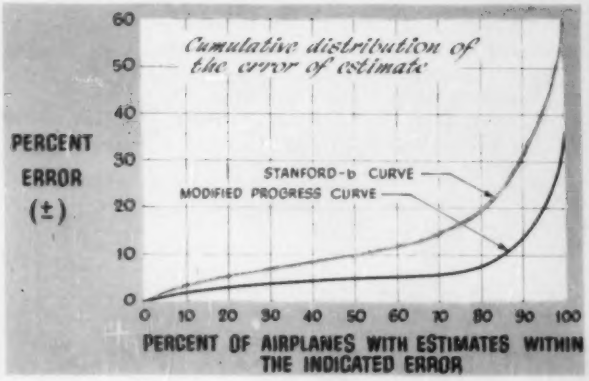

FIGURE 6

The number of drawings in each of the foregoing groups is 10,000. From the given data,

$$D^B = \sum_{i=1}^{7} D_i^B \delta_i^B = 3{,}000 + 7{,}000 + 4{,}000 + 6{,}000 = 20{,}000$$

$$k^B = \frac{Y_f}{D^B(1+b)^n} = \frac{200{,}000}{20{,}000(1+4)^{-.500}} = 22.3$$

For unit 3,

$$x_A = 2$$
$$x_B = 1$$

Using Eq. 20.,

$$Y_B = 22.3[10{,}000(1+4)^{-.500} + 10{,}000(3+4)^{-.500}] = 185{,}000$$

For unit 4,

$$x_A = 2$$
$$x_B = 2$$
$$Y_B = 22.3[10{,}000(2+4)^{-.500} + 10{,}000(4+4)^{-.500}] = 170{,}000$$

For unit 8,

$$x_A = 3$$
$$x_B = 3$$
$$x_C = 2$$
$$Y_B = 22.3[3{,}000(10)^{-.500} + 7{,}000(12)^{-.500} + 4{,}000(7)^{-.500} + 6{,}000(9)^{-.500}] = 145{,}000$$

Airplane Version C (Cumulative unit numbers 5, 6 and 9)

From the given data,

$$D^C = 3{,}000 + 7{,}000 + 6{,}000 + 5{,}000 = 21{,}000$$

$$k^C = \frac{200{,}000}{21{,}000(1+4)^{-.500}} = 21.2$$

For unit 5,

$$x_A = 2$$
$$x_B = 2$$
$$x_C = 1$$
$$Y_C = 21.2[3{,}000(7)^{-.500} + 7{,}000(9)^{-.500} + 6{,}000(7)^{-.500} + 5{,}000(5)^{-.500}] = 170{,}000$$

For unit 6,

$$x_A = 2$$
$$x_B = 2$$
$$x_C = 2$$
$$Y_C = 21.2[3{,}000(8)^{-.500} + 7{,}000(10)^{-.500} + 6{,}000(8)^{-.500} + 5{,}000(6)^{-.500}] = 158{,}000$$

For unit 9,

$$x_A = 3$$
$$x_B = 3$$
$$x_C = 3$$
$$Y_C = 21.2[3{,}000(10)^{-.500} + 7{,}000(13)^{-.500} + 6{,}000(10)^{-.500} + 5{,}000(7)^{-.500}] = 142{,}000$$

The man-hour estimates can now be summarized:

Cumulative Unit No.	Airplane Version	Estimated Man-hours
1	*A*	200,000 (known)
2	*A*	183,000
3	*B*	185,000
4	*B*	170,000
5	*C*	171,000
6	*C*	158,000
7	*A*	149,000
8	*B*	145,000
9	*C*	142,000

OBSERVATIONS ON THE MODIFIED PROGRESS CURVE

The modified progress curve developed in this article suffers from the following limitations:

1. It assumes that the learning experienced on any component is fully retained, no matter how much time elapses before the same work is repeated. Modifying the assumption will lead to a more cumbersome formulation and has not been attempted.
2. When the number of versions in a family of airplanes gets large, the computations become extensive. The difficulty is relieved if attention is restricted to a small number of versions in combination with the version to be estimated. These will be ones which share the most work with this version and contribute the most experience.

Engineering drawing count was used as a measure of a_i for the 707 program. This device is not a necessary part of the modified progress formula. Any other available

measure of design changes (which provides satisfactory results) may be chosen.

CONCLUSIONS

Design changes may have a marked effect on labor requirements in an aircraft production program. The estimating formula commonly used in the aircraft industry has been modified so that this fact can be taken into account in a systematic manner.

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Industrial Research on the Effects of Pace on Work Sampling Results[1]

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WORK SAMPLING is a random sampling method of getting facts about an activity. This method is based upon the fact that the percentage distribution of the various elements, as they occur during random observation, tends to equal the exact percentage distribution that would be found by continuous observation.

Ratio-delay was the term applied to this snap observation method originally developed in 1935 by Tippett in the British textile industry. As originally introduced by practitioners in this country, ratio-delay was used mainly for developing time study allowances for the categories of delay and irregular occurrence. The method was widely adopted because it afforded a method for more easily and accurately determining these allowances.

In July, 1952, *Factory Management and Maintenance* introduced the term Work Sampling. Work sampling actually involves the same technique and approach as ratio-delay, but the term expanded the general use and application of this procedure. Ratio-delay had ordinarily been used to study machine "activities." Work sampling extended this use to cover the study of human activities, ordinarily non-repetitive in nature, but applicable to any type. Work sampling became a fact finding tool, and a means for making utilization studies of both equipment and personnel. Such information helps find better methods and assists in training, selection, and overall evaluation.

Although essentially the same technique, the accuracy and precision requirements for ratio-delay are greater than for general work sampling. Time standards require more accurate results than do general fact-finding, work analysis, or utilization studies.

CURRENT USES OF WORK SAMPLING

The original application of work sampling has been expanded by many persons to cover many activities. The following is a categorical classification of some of the more prevalent uses of work sampling. However, this list does not exhaust the present or future applications of work sampling.

1. Time Standards

The establishment of time standards generally includes an allowance to the basic work time for miscellaneous work or necessary delays. These data are obtained using work sampling, with results in the form of a percentage of the daily time spent on the occurrences in which interest is expressed. Repetitive work time study is being accomplished by using the work sampling technique and an average performance index that is established through rating, as the random observations are made.

2. Fact Finding

The use of work sampling for fact finding or other non-repetitive work, sometimes called an "occurrence study," differs from other applications in that the observer never knows beforehand all of the activities performed by the individuals being studied.

Random sampling is being used to measure the variation of operators from the standard method determined for the job. In this application the method is the thing that is sampled.

Work sampling studies are being made with a motion picture camera. A randomly punched tape is being used to activate the camera shutter at random intervals, thus recording on film the information required.

Before work simplification can be used to devise a better method, one must have the facts about the present method. Work sampling is being used to locate the best opportunities for savings through better methods.

Work sampling is being used to verify production control records. Each day ten cards, in a Kardex file, are checked by using a ruler and a table of random numbers to select the cards. Each number drawn from the random number table is the num-

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ber of inches to the next card to be verified.

3. Utilization Studies

Machine utilization is becoming an increasingly fertile field for the application of work sampling, as industry becomes more automated. The technique is used to tell quickly the location, relative magnitude, and causes of the more serious production bottlenecks.

Work sampling is being used to find how people such as foremen, engineers, nurses and maintenance personnel, spend their time. This type of study makes it possible to reassign duties to provide for the utilization of personnel at their highest capacity for a greater part of their work day.

Another approach to personnel utilization is the evaluation of job knowledge of key personnel through the use of random telephone inquiries. A top executive asks the same question of each key person and a record is kept, over a period of time, to evaluate these people.

Supervisor training is being supplemented through the use of work sampling. Foremen are used as observers to randomly record "work" and "idle" time for the men they supervise, thus establishing and illustrating the true percent of time the men actually are working.

SOME ASSUMPTIONS OF WORK SAMPLING

Work sampling has always involved several assumptions, some of which can be controlled, and some of which have not been checked. For example, until recently, work sampling has assumed that the "process" of operators, machines, or combinations was stable. However, it has been shown that a statistical procedure, similar to quality control charting, can be used to check this assumption.

One problem, never completely checked, concerns the assumption that the proportionality results of a work sampling study will remain the same regardless of the pace of the operator(s). Will operator *A* at 150% pace spend the same percent of time in Activity *X* as operator *B* at 75%? Professor Morrow of New York University recognized this factor when he conducted verification studies of work sampling in industry. A more recent analysis indicated that the use of the binomial formula alone in work sampling ignores sources of large error, such as the variation among men, and the day-to-day variation of men. Even work on therblig relationships has indicated that the proportion of time for each therblig does not remain the same for different operators performing the same job at different paces. These results would seem to indicate that the time proportionality of *elements*, such as those used in work sampling, changes at different paces.

For many of the uses of work sampling, like fact-finding, analysis of non-repetitive work, etc., the effects of pace on work sampling are not important. For example, when work sampling helps determine how people such as foremen, engineers, nurses, and maintenance personnel spend their time, not too much difficulty can arise because of this assumption. However, when work sampling is used for delay or irregular occurrence allowances in time study, machine or personnel utilization objectives, and labor quotas (actual establishment of time standards), such an assumption, if not correct, can cause difficulty.

One method suggested for minimizing this problem is to make a large number of observations on a large number of operators performing the same type of work. There is no doubt the combination of operators, performing similar work, into a single study, will reduce the *cost* of obtaining a large number of observations. Very little time is required, in most cases, for random observations of several operators as compared with a random observation of a single operator; travel time is reduced for the analyst. Although this may help reduce the error, the problem looms large when one realizes that the number of people on most jobs or operations is relatively small, normally only one or two.

RESEARCH PROCEDURE

The author conducted an industrial research investigation to determine if operator pace affects the proportions of time spent performing various activities usually listed in work sampling studies.

The jobs used in this investigation were not changed in any way prior to making the studies, and the regular company time study personnel were used, whenever possible. In this way the intent of this research could be met more adequately since actual rating and work sampling results would be obtained for the industrial jobs, as they were being used currently in industry.

Four jobs, each with common traits, were selected in four different industries. The criteria for selection of the jobs were as follows:

1. The job is generally repetitive in nature.
2. Five or more operators are assigned to the same operation.
3. The performance of the job does not require a crew; that is, each of the operators assigned to the job is performing the same work at different work stations.
4. Each operator is fully trained according to the concept of full training for the company.
5. The work of the job is manual and fully controlled by the operator.
6. The operators working on the job are paid on an incentive basis, if possible.
7. The work is continuous enough to permit observations to be made over several weeks.
8. Incoming material quality is reasonably constant.

The first job selected was making green sand molds for automobile piston ring castings, using a squeeze machine molder. The rating system used in this plant involved the multi-image or step film procedure. The total number of observations made on the sixteen different operators involved was 7,610.

Differences in method were quite evident among the operators as there had been no policing of the best method. Some of the high producers obtained their production easily by smoothly coordinated simultaneous body member motions, while others produced about the same amount of production with faster, jerky uncoordinated individual motions.

The second job selected was a hand assembly of several washers, nuts and a diaphragm to produce a total dia-

phragm assembly for an automobile carburetor. The entire assembly was secured, while in the jig, by means of an arbor press.

The rating system used in this plant was based upon the judgment of speed made by observers who were accustomed to observing hand assembly operations. There were no visual or written bench marks of the levels of speed, but coordination among the observers was maintained through periodic rating sessions held at a work place. A total of 2,455 observations were made on the total of seven operators studied. The number of operators on any given day varied due to fluctuations in the work load. All operators were well trained in the proper method of assembly before they were placed on the incentive plan. As a result, the methods used by the various operators were rather consistent.

The third job consisted of punching IBM cards for a daily production control report. The rating system used was the same as that presented for mold making, although the card punching took place in another plant. Frequently it was difficult to rate the operators, as mental activities seemed to be controlling the movement of the body members. This job was included in order to present a clerical, office type activity that was more non-repetitive in nature than the others. The workers were hourly paid and production was not compared to a time standard. A total of 1,783 observations was made for the five operators involved.

The methods were not consistent from operator to operator, such as one operator turning pages of a source document with the left hand while continuing to punch with the right, as compared to other operators that stopped punching with the right hand and turned pages with the same hand to interrupt the punching sequence. The operators who punched cards at a high pace seemed to take a greater interest in their work as they took less personal time than the lower paced operators.

The fourth job was the insertion of a polyethylene bag inside a paper bag, to be used for packaging powdered milk for the bakery industry. The rating system used in this plant was based upon a judgment of skill and effort. The total of 1,673 observations was made on eight different operators. The job was paid on an incentive plan. Methods were rather inconsistent, with some operators using fast, jerky individual motions and others using smooth simultaneous motions. There were no methods training, procedures or policing methods.

The regular work sampling procedures were followed to obtain the work sampling results. After making the instantaneous observation, the time study observer rated the job element, using the company's particular rating technique. The observer would attempt to rate the balance of the element initially observed or he would wait until that element reoccurred in the next cycle. If a rating was not obtained on the next reoccurring cycle, successive cycles would be observed until a rating was obtained.

Probably the best way to describe the rating procedure is to say it was close to an instantaneous rating. This was done because there was no alternative procedure available.

The operators on the jobs were informed of the Work Sampling experiment before the observations were started. All questions were answered freely. The operators were urged to proceed with their work in a normal manner as though there were no observer present. In all cases the operators appeared to behave naturally, largely due to the extended period of time taken for the observations.

Random observation times were obtained by writing each of the minutes of an hour on the back of a playing card, shuffling the cards thoroughly and drawing the required number of random times.

The observed data were transferred to IBM cards for analysis and calculations using a model 650 IBM computer.

RESEARCH RESULTS

Ratings, even when made under optimum conditions, are subject to many errors. As obtained in this experiment, the ratings involve still more possibilities for errors. Yet it is essential to make several checks on the ratings to assure that they were obtained with as great a validity as possible. When ratings are made instantaneously, there would seem to be a tendency for the ratings to be more alike for a given individual for a given element for the various samples than would be expected in the normal pattern of variation.

Analysis of the ratings for a general pattern of individual differences, using the arithmetic average and standard deviation, indicated that the rating values did show expected differences and would be usable. $\overline{X}$ and R Chart calculations indicated that there were no assignable causes affecting the ratings. Analysis of variance results indicated significant difference among operators, as should be expected. Simple correlation of output and pace indicated fairly high correlations for most jobs, as should be expected. As a result of these calculations it was assumed that the ratings were valid.

Analysis of the Work Sampling results showed a level of error comparable to that commonly accepted in industry for work measurement purposes. P Chart calculations showed no significant amount of a day's data to be out of control. Thus the work sampling portion of the experiment was assumed to be valid.

Now that the pace and work sampling results were verified it was possible to proceed to the crux of the investigation! The technique of simple correlation was used to determine the relationship between the two variables of pace and percent time for each operator, and whether this relationship was significant. The correlation between pace and work sampling results showed the highest significance for the elements not highly repetitive and in which the operators obtained materials whenever they

needed them. The correlations were lowest for the highly repetitive elements.

CONCLUSIONS

The research had certain limitations due to inconsistent operator methods, questionable rating systems and lack of overseeing observers. The following conclusions may be drawn, subject to the limitations:

1. Methods variations or skill of operators performing irregular elements are important in determining amount of time spent on irregular elements.
2. Pace does not affect percent of time for an occurrence on highly repetitive elements.
3. Pace has a greater effect on percent of time for an occurrence which is not highly repetitive (which usually infers that methods were not standardized).
4. When work sampling is used for setting allowances, as for time standards, it is important to standardize methods. It is interesting to note that this precaution has been recommended, for some time, for taking time studies to establish standards. Yet this precaution is not generally stated in work sampling literature; in many cases work sampling is used because it is felt that standardization can be overlooked.
5. Repetitive elements give greater spread in pace than non-repetitive elements.
6. When pace considerations are involved, non-incentive clerical work is not as adaptable to the work sampling technique as to incentive paid factory work. The data were very limited in this area.
7. There is some slight indication that the faster operators, on non-incentive work, spend less time on personal needs.

DISCUSSION

In terms of the uses of work sampling, several important inferences may be drawn. It would appear quite satisfactory to use work sampling for obtaining the time values for elements of a repetitive nature in a long run job. Likewise, any uses of work sampling for analysis or fact-finding would not usually be affected by any of the results of this research. It is probably inconsequential that a difference may occur in some of the percentage values when the study is used for fact-finding.

However, when work sampling is to be used for establishing time standards for jobs with many relatively non-repetitive elements, the conclusions of this experiment indicate that improper time values (either for the elements or for allowances) can result. Great care should be exercised in standardizing methods, checking results, selection of operators for the study, and so forth.

Work sampling has already established itself as an exceptionally useful technique. In the haste to use it for an ever-increasing number of situations, many errors may be committed unwittingly. It is hoped that further research will help set the patterns of caution to be employed by those applying work sampling.

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Inventory Reorder Points for Conditions of Variable Demand and Lead Time*

by **DAVID C. EKEY**

Professor of Industrial Engineering, Georgia Institute of Technology

JOSEPH B. TALBIRD

Industrial Engineer, Operations Research Incorporated

and **THOMAS L. NEWBERRY**

Assistant Research Engineer, Georgia Institute of Technology

THE INVENTORY policy to be considered in this article is that of the fixed quantity type. This policy specifies that the inventory is to be examined continuously; and upon declining to a predetermined level, a fixed quantity of goods is ordered.

The work presented is concerned with only a small segment of the possible applications of inventory control. For an interpretation of the scope of the general field of inventory control, refer to (3).

In general the reorder point consists of two parts—the quantity of items corresponding to the expected demand during the expected lead time and the safety stock. Reorder points may be computed either by considering the actual cost of the shortage or by specifying the tolerated probability of a shortage. The latter approach will be considered here.

Obviously, when the reorder points are computed on the basis of a management decision which specifies the tolerated probability of a shortage, cost minimization does not necessarily result. Often a secondary criterion exists, provided profits are reasonable, which discourages frequent stock-outs and shortages, regardless of the actual cost of a shortage. In many instances the cost of a shortage includes intangibles, such as good will, thereby making the cost minimization criterion, if it exists, extremely difficult to achieve. The probability of a shortage approach to this specific inventory policy may be useful when the cost of a shortage is difficult to estimate and when the stockage criterion is not direct cost minimization.

The purpose of this article, subject to the foregoing conditions, is:

1. To consider the analytical development required for computing the reorder point.
2. To present numerical results of this analytical development under special conditions of Poisson demand and lead time.
3. To illustrate the use of these numerical results.

The order quantity calculation is not considered in this article. Various criteria that may be used in selecting the order quantity for inventory items are:

1. To minimize the sum of carrying costs and ordering costs.
2. To minimize carrying costs given that a specified number of orderings will be made.
3. To minimize the number of orders placed given that a specified inventory investment will be maintained.
4. To order in quantities which are primarily determined by the capacity of the shipping container.

PROBABILITY OF A SHORTAGE DURING REORDER CYCLE

Figure 1 is a pictorial representation of a typical distribution of demand (continuous variable) given a particular lead time (discrete variable). This combination of a continuous demand distribution and a discrete lead time distribution has been selected because of the sim-

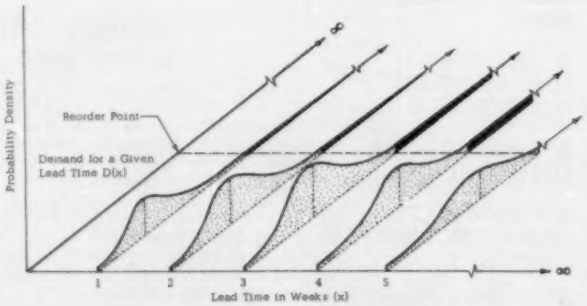

FIGURE 1. A Pictorial Representation of a Typical Inventory Model for Varying Lead Time and Demand.

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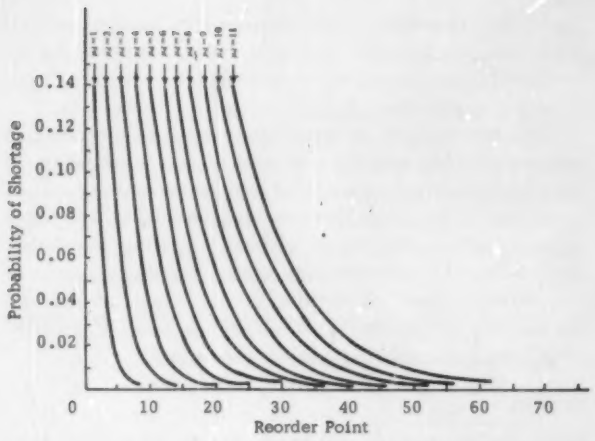

FIGURE 2. Graph of Three Variables; Probability of a Shortage, Mean μ_d of a Poisson Demand Function, and the Reorder Point with the Poisson Lead Time Held Constant, $\mu_x = 1$.

plicity of illustration. Let the following notation be introduced:

x = lead time random variable.
d_i = demand random variable during time unit i.
$D(x)$ = demand random variable given that the lead time is x units.
μ_x = expected value of x.
μ_d = expected value of d_i.
$\mu_{D(x)}$ = expected value of $D(x)$.
$P\{s\}$ = probability of a shortage during a reorder cycle.
$P\{s \mid x\}$ = probability of a shortage during a reorder cycle given that the lead time is x time units.
$f(x)$ = lead time probability density.
$g[D(x)]$ = demand probability density during lead time.
R.P. = reorder point.

The conditional probability of a shortage for a given lead time is

$$P\{s \mid x\} = \int_{D(x)=\text{R.P.}}^{\infty} g[D(x)]dD(x). \qquad \text{Eq. 1.}$$

This area is represented in Figure 1 by the shaded tail of the distribution to the right of the reorder point line. By multiplying Eq. 1. by $f(x)$ and summing over all values of x, we obtain

$$P\{s\} = \sum_{x=0}^{\infty} f(x) \int_{D(x)=\text{R.P.}}^{\infty} g[D(x)]dD(x). \qquad \text{Eq. 2.}$$

Since the total demand during lead time is

$$D(x) = d_1 + d_2 + \cdots + d_x; \quad \text{then}$$
$$\mu_{D(x)} = x\mu_d. \qquad \text{Eq. 3.}$$

For the special condition of Poisson demand and lead time, we have

$$f(x) = e^{-\mu_x}(\mu_x)^x/x! \quad \text{and} \qquad \text{Eq. 4.}$$

$$g[D(x)] = e^{-\mu_{D(x)}}[\mu_{D(x)}]^{D(x)}/D(x)!. \qquad \text{Eq. 5.}$$

Substituting Eq. 3. into Eq. 5. results in

$$g[D(x)] = e^{-x\mu_d}(x\mu_d)^{D(x)}/D(x)!. \qquad \text{Eq. 6.}$$

By considering Eq. 2 as a discrete function

$$P\{s\} = \sum_{x=0}^{\infty} f(x) \sum_{D(x)=\text{R.P.}+1}^{\infty} g[D(x)]. \qquad \text{Eq. 7.}$$

When Eq. 4. and Eq. 6. are substituted into Eq. 7., we obtain

$$P\{s\} = \sum_{x=0}^{\infty}\left(\frac{e^{-\mu x}(\mu_x)^x}{x!}\right)\left(\sum_{D(x)=\text{R.P.}+1}^{\infty}\frac{e^{-x\mu d}(x\mu^d)^{D(x)}}{D(x)!}\right). \qquad \text{Eq. 8.}$$

By use of Eq. 8. several sets of curves (Figures 2 and 3) have been calculated for a specific region of Poisson parameters from which reorder points can be determined for a given probability of a shortage. These curves were calculated partially by desk calculator and partially by an electronic computer.

PROBABILITY OF SHORTAGE DURING TIME PERIOD T

Consider that N orders are to be placed during time period T, suppose that it is desired to compute a reorder point such that the probability of one or more shortages during T will be equal to P^*. If $P\{s\}$ is the probability of a shortage occurring during a reorder cycle, then

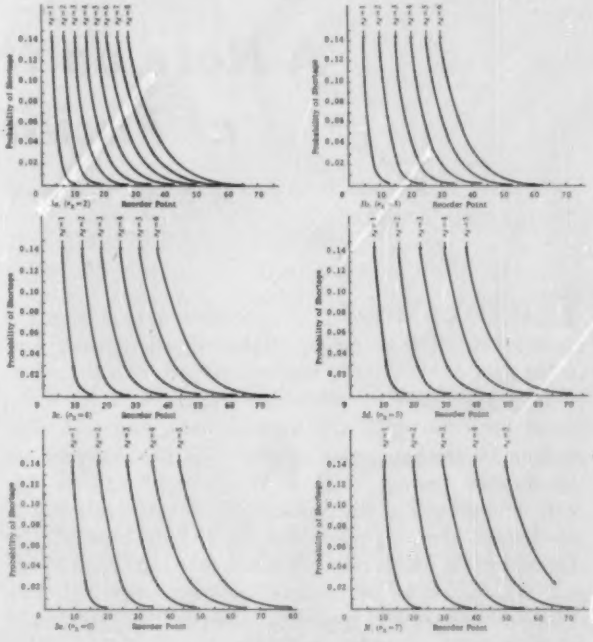

FIGURE 3. Graph of Three Variables; Probability of a Shortage, Mean μ_d of a Poisson Demand Function, and the Reorder Point with the Poisson Lead Time Held Constant.

$[1-P\{s\}]^N$ is the probability of no shortage occurring during the time period T; therefore

$$P^* = 1 - [1 - P\{s\}]^N \qquad \text{Eq. 9.}$$

EXAMPLE

Given the following data, find the reorder point so that the probability of a shortage during one year is 0.20.

1. Demand per week—Poisson distribution with an average of 4 units per week.
2. Lead time—Poisson distribution with an average of 5 weeks.
3. Orders per year (N)—6 orders.

Substituting into Eq. 9., we have

$$0.20 = 1 - [1 - P\{s\}]^6, \quad \text{or}$$

$$P\{s\} = 0.0365 \qquad \text{Eq. 10.}$$

From Figure 3d. it can be seen that

$$\text{R.P.} = 39 \text{ units.}$$

An imputed cost of a shortage can be computed for any specified probability of a shortage. Comparisons can be made between different specified probabilities of a shortage on the basis of imputed shortage cost.

In this article attention has been restricted to that of computing reorder points for a special class of inventory problems where the Poisson distribution for demand and lead time is applicable. A similar type of analysis can be extended to conditions where different statistical distributions are applicable.

This development assumed individual demands which are independent and for one unit of the commodity. If several demands are generated simultaneously, the stock level may be less than the reorder point before the order quantity is actually placed, thereby resulting in a larger probability of a shortage than stated. Further research in the determination of reorder points when several demands may be generated simultaneously would contribute to the present knowledge in this area.

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A Note on the Assignment of Facility Location[1]

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TRAVEL CHARTING is a semi-analytical tool for plant layout. The literature on the subject is sparse and in the past has primarily been concerned with the selection of appropriate measures and criteria, with the manner of presentation of the working data, and with suggestions for trial and error solutions (1) (3). A recent article in this *Journal* by R. J. Wimmert offers a mathematical approach to the problem (4). It is the purpose of this presentation to point out the incorrectness of the theorem upon which that approach is based, and to suggest and prove an alternative theorem. Although this theorem suggests an approach to the problem and should be useful to anyone who has to solve such a problem it cannot be considered a solution to the facility assignment problem.

PROBLEM STATEMENT

We are given N different facilities (machines, machine groups, departments, plants, etc.) and N different locations each of which can accommodate one facility. Our problem is to assign facilities to locations. We assume that the "distance"[2] between all pairs of locations, and the "traffic"[3] between all pairs of facilities is known. The "value" of an assignment is given by the sum of the

[1] This work was in part supported by the Office of Naval Research under Task NR 047-023.

[2] Distance is used in a general sense which can include physical distance, time, cost, or some index of difficulty of transfer.

[3] Traffic can be number of trips, volume, weight, etc.

traffic×distance products for all pairs of facilities. We seek an assignment to make this value as small as possible.[4]

There are a considerable number of possible assignments. For example, for $N=10$ there are 3,628,800 different assignments of facilities to locations. Even granting that 99% of the possible assignments are for some reason obviously inadmissible, there would remain some thirty-two thousand possibilities. A systematic method of selection is highly desirable.

METHODS OF DETERMINING AN ASSIGNMENT

Consider now the $n=N(N-1)$ different paths[5] between pairs of locations. Let $A_1, A_2, \cdots, A_n$ represent the length of these paths *ranked* so that $A_1 \geqq A_2 \geqq A_3 \geqq \cdots \geqq A_n$. Consider the $n=N(N-1)$ pairs of facilities. Let $B_1, B_2, \cdots, B_n$ represent the traffic between these pairs *ranked* so that $B_1 \leqq B_2 \leqq B_3 \leqq B_4 \cdots, \leqq B_n$.

Let X be an $n \times n$ matrix such that:

$$x_{ij} = A_i \cdot B_j$$

Methods of determining an assignment can be based upon special properties of this matrix. Any assignment can be indicated on this matrix by the specification of n appropriate elements of the matrix. For example, if facility C is assigned to location 2 and facility D to location 4, then the element of X corresponding to pair C-D and path 2-4 would be one of those specified. The n elements which describe an assignment will be such that there will be one in each column and one in each row of the X matrix. The sum of these n elements will be the "value" of the assignment. Unfortunately, the converse is not true: any n elements with one in each column and one in each row do not necessarily correspond to an assignment.

Our problem can now be stated in the following manner: Find the n elements of X, taking one from each row and one from each column, which correspond to an assignment of facilities to locations and whose sum is a minimum.

Given a set of n elements from X it is relatively easy to determine whether or not they represent an assignment. Thus, if one had a method of determining the small sum sets of n elements (one from each row and one from each column) from X one could simply examine successive sets (preferably starting with the set with the smallest sum, then the second smallest, etc.) until a set is discovered which corresponds to an assignment. Wimmert claims to offer just such a procedure (4).

However, Wimmert's procedure appears to be based on the following theorem[6] (4, pp. 498-9):

Consider a matrix Y whose elements are defined:

y_{ij} = the minimum sum of n elements of the X matrix, one from each row and one from each column, which includes x_{ij}

The elements of Y are monotonic nondecreasing with distance from the principal diagonal; i.e. elements in any given diagonal are not less than any element in a diagonal which lies closer to the principal diagonal.

That this is not a true theorem is perhaps most easily shown by means of a counterexample:

Consider the X matrix

A_i \ B_i	1	2	3	4	5	6
10	10	20	30	40	50	60
5	5	10	15	20	25	30
4	4	8	12	16	20	24
3	3	6	9	12	15	18
1	1	2	3	4	5	6
1	1	2	3	4	5	6

The resulting Y matrix is

i \ j	1	2	3	4	5	6
1	55	60	66	73	82	91
2	60	55	56	58	62	66
3	62	56	55	56	59	62
4	65	58	56	55	57	59
5	73	64	60	57	55	55
6	73	64	60	57	55	55

Note that $y_{12}=60$ is greater than $y_{24}=58$, $y_{13}=66$ is greater than $y_{25}=62$, and $y_{14}=73$ is greater than $y_{26}=66$, all contrary to the assertion of the theorem.

The following is a true theorem about the Y matrix:

For any element y_{ab} which is on or above the principal diagonal

$$y_{ab} \leqq y_{ij} \quad \text{for all} \quad i \leqq a; \qquad j \geqq b$$

For any element y_{mn} which is one or below the principal diagonal

$y_{mn} \leqq y_{ij}$ for all $i \geqq m$; $j \leqq n$ (For proof, see Appendix.)

As a practical procedure one would not obtain the Y matrix, but would use this property of Y as a guide in selecting sets of n elements from X. The minimum sum set of n elements from X (one from each row and column) are the elements of the principal diagonal. If one is sufficiently lucky to have this set of elements correspond to an assignment, the problem is solved. Lacking this good fortune, the known property of the Y matrix suggests that we begin our search for a small sum set which corresponds

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[4] This is similar to both the "assignment" and the "traveling salesman" problems. The similarity is discussed in (2).

[5] In the special case with symmetric distance and traffic matrices the number of paths is $n=N(N-1)/2$.

[6] The theorem is stated in terms of the present notation and description, not as Wimmert phrased it. We believe it to have exactly the same meaning.

to an assignment in the neighborhood of the principal diagonal and work out systematically from there.

The theorem suggests that the minimum sum set which includes a particular element should be favorable; there remains the problem of obtaining this set since for any particular element there are $(n-1)!$ different sets which take one from each row and one from each column. However, since the theorem also applies to the other members of the set (after the first) it has the stronger suggestion that all members of the set be close to the principal diagonal.

APPENDIX

We are given a monotonic decreasing sequence $A_1, A_2, \cdots, A_n$, a monotonic increasing sequence $B_1, B_2, \cdots, B_n$, and a square matrix X of order n with

$$x_{ij} = A_i \cdot B_j$$

We are interested in selecting from X sets of n elements, taking one element from each row and one from each column. Define a square matrix Y of order n as follows:

y_{ij} = the minimum sum of n elements of X, one from each row and one from each column, which includes x_{ij}.

There is a well-known result of elementary algebra to the effect that the minimum sum of the pairwise products of two sequences is obtained when the ranked elements of one sequence are combined pair by pair with the reversely ranked elements of the other sequence. Thus for $\{A_i\}$ and $\{B_j\}$ the minimum sum of n pairwise products is obtained by pairing A_k with B_k for $k=1, 2, \cdots, n$. This established that

$$\underset{i,j}{\text{minimum}}\, y_{ij} = y_{ii}, \qquad i = 1, 2, \cdots, n$$

That is, the minimum elements of Y are located on the principal diagonal, and all the elements on the principal diagonal are equal. The minimum sum set of n elements from a matrix of the form of X is the n elements of the principal diagonal.

The minimum sum set including any given element of X can be simply obtained by deleting from X the row and column which contain that element. The remaining submatrix is again of the form of X and its minimum sum set of $n-1$ elements consists of the elements of its principal diagonal.

$$y_{ij} = x_{ij} + \sum_{k=1}^{i-1} x_{k,k} + \sum_{k=i+1}^{j} x_{k,k-1} + \sum_{k=j+1}^{n} x_{k,k} \quad \text{for} \quad i \leqq j$$

Now consider two elements of X; x_{ab} with $a \leqq b$ and x_{ij} with $i \leqq a$ and $j \geqq b$.

$$y_{ij} - y_{ab} = \left[x_{ij} + \sum_{k=1}^{i-1} x_{k,k} + \sum_{k=i+1}^{j} x_{k,k-1} + \sum_{k=j+1}^{n} x_{k,k} \right] - \left[x_{ab} + \sum_{k=1}^{a-1} x_{k,k} + \sum_{k=a+1}^{b} x_{k,k-1} + \sum_{k=b+1}^{n} x_{k,k} \right]$$

Upon collecting and grouping terms

$$y_{ij} - y_{ab} = \left[x_{ij} + \sum_{k=i+1}^{a} x_{k,k-1} + \sum_{k=b+1}^{n} x_{k,k-1} \right] - \left[x_{ab} + \sum_{k=i}^{a-1} x_{k,k} + \sum_{k=b+1}^{j} x_{k,k} \right]$$

Both of the expressions in brackets represent combinations taken from a submatrix which has the form of X, and which consists of the rows $m, m+1, \cdots, a-1, a, b+1, \cdots, n-1, n$ and columns $m, m+1, \cdots, a-1, b, b+1, \cdots, n-1, n$. In the submatrix all of the terms in the second bracket lie along the principal diagonal, hence represent the minimum sum combination for that submatrix. As a result the right hand side of the equation is always non-negative and this establishes the fact that

$$y_{ij} \geqq y_{ab}$$

A similar and symmetric argument may be offered for y_{mn} where $m \geqq n$.

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Industrial Engineering Technologies for the College Curriculum*

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GRANTING the inclusion of language, mathematics, physics, chemistry, mechanics, electricity and metallurgy (or more broadly materials) in the Industrial Engineering curriculum, what specialized Industrial Engineering technologies should be added? Not so long ago, the specific technologies that had been formulated in the field were not only limited in number but also did not match in scientific content and interest the specialized technologies of other branches of engineering. Lacking a body of specialized, challenging technologies of its own, a number of the Industrial Engineering departments leaned outward from the main core of interests toward industrial administration, economics and metallurgy.

The accelerating growth of the last 25 years now confronts the schools with more substantial material for specialized Industrial Engineering technologies than they have been able to organize into course material and more than they can incorporate into the undergraduate curriculum. The schools that are not so far advanced wait for the material to be formulated and published by faculties of the more advanced schools. Of course it is not to be expected that all schools will or should arrive at the same selection or emphasis of subjects.

The faculties who have responsibility and authority will make the choice. But how should they choose between the needs of small industry, many of whom want broadly trained engineers, and the needs of large concerns who use many specialists? How should they choose between the industries who dominate the area where their school is located and the industries of the country as a whole? Should the education be that which can most probably be applied immediately or that which will be needed if and when the graduates become experts and supervisors?

Presumably, the selection of subjects will provide a well-balanced foundation for organizing and operating an industry—primarily, but not necessarily—of the manufacturing kind. One premise in the selection is that large industries can and do teach starting engineers specific technologies or approaches to their problems, but that they seldom teach the basics of administration and economics. A second and somewhat contradictory premise holds that engineers should be trained at college in those technologies of Industrial Engineering which are most likely to be applied within a few years after graduation. The dangers of adopting either premise too wholeheartedly have had many expositions. This discussion adopts a premise that the subject matter for the specialized Industrial Engineering technologies should be worthy of treatment at the upper-class level and that courses in administration and economics beyond the introductory level should be deferred to graduate school when they can be treated in depth, or to the time when they can be directly associated with the individual's opportunities and needs. The five year engineering course, let alone the four year course, does not have enough hours to train more than superficially in Industrial Engineering and business administration simultaneously.

TECHNOLOGIES OF HOW TO MAKE

The activities in which the Industrial Engineer will find most probable need and demand for his services after graduation are listed in Figure 1. The list differs but little from the subjects one finds in one or a combination of several Industrial Engineering curricula. The columns to the right look at the subjects from the points of: training objective, time of use in relation to graduation, and the major prerequisite studies. The listing follows roughly the timing in which the items might appear in a curriculum and might occur in the development of the engineer's professional experience. Discussing the order could be long and interesting, proceeding along the lines of ends versus means, inductive versus deductive, building block versus general concept approaches, but will not be pressed here.

The subjects are divided into three categories—*A*, *B*, *C*. Category *A* includes the basics for knowing how to make an industrially manufactured product. It gives some foundation for judging when to cast and when to machine, for deciding when to punch or to drill, for knowing

* *Editor's Note:* This article is a continuation of the discussion developed by the author in his article, "Basic Preparation for Industrial Engineering Curricula," published in the May-June, 1960, *Journal of Industrial Engineering*.

	Category			For Use		Applying Basic Studies of
	A	*B*	*C*	*Immediate*	*Future*	
Basic processes	x			x		Mathematics, Physics and Chemistry, Mechanics, Materials
Dimensional Control	x			x		Mathematics, Physics and Chemistry, Mechanics, Materials
Motion economy	x			x		Mechanics
Quality assurance	x			x		Mathematics, Mechanics, Materials
Cost accounting	x	x		x		Mathematics
Manufacturing equipment	x	x		x		Mathematics, Physics and Chemistry, Mechanics, Materials
Material handling		x		x		Mathematics, Mechanics, Materials
Factory layout		x		x		Mathematics
Labor grading		x			x	Mathematics, Language, Psychology
Wage practices		x			x	Mathematics
Industrial organization		x	x		x	Human Relations, Psychology
Dispatching, Scheduling, Programming			x		x	Mathematics
Industrial and labor relations			x		x	Human Relations, Psychology
Product design			x		x	Mathematics, Physics and Chemistry, Mechanics, Metallurgy
General accounting			x		x	Mathematics, Economics
Results measurement and control			x		x	Mathematics
Data processing			x	x		Mathematics
Operations research	x	x	x		x	Mathematics, Physics and Chemistry, Logistics
Engineering administration			x		x	Human Relations, Psychology
Marketing			x		x	Mathematics, Language
Business law			x		x	History, Language, Logistics
Business finance			x		x	Mathematics, Economics
Business administration			x		x	Human Relations, Psychology

FIGURE 1. Major Subjects and Activities of Industrial Engineering.

whether a cut-to-length operation should be done before or after a forming operation, for knowing what accuracies can be maintained in production by punching, drilling, reaming, grinding, electroplating, and so on for the main processing operations of manufacturing. This knowledge is basic to the Industrial Engineer. An analogy for the heat-power engineer is to know whether coal or oil should be used with a given combustion space for a boiler; or, for a machine designer, whether to use a gear train and friction plate clutch instead of a hydraulic coupling.

When entering industry, the Industrial Engineer most likely will first be entrusted with minor modifications to steps of manufacture of a given product, using the usual industrial processes. He may then have to introduce into manufacture a new item that differs but little from similar products already in production. Later he may be turned loose to reduce the cost of a wide variety of products by methods he can prove to be safe, economical and productive of good quality.

The development aspect of this category should not be overlooked. High temperature engines, supersonic airplanes, transistors, high frequency vacuum tubes, television screens, and atomic reactors in quantity owe their existence to the development of new processes as well as new designs and materials. Many laymen and many engineers take it for granted that we can make anything the tutored or untutored inventor and scientist can design. That is not so. We have the science to design a rocket to circle the moon, but we cannot yet make so complicated a device, at least one that works with predictable reliability. Perhaps we can say with some confidence that there will be one that works as predicted if we make a thousand of them. For industrial purposes, however, that is the same as saying that now we do not know how to make such a rocket. Doubtless we shall learn. But when we do, it will be the result of millions of manhours of development effort in this category, not to mention the other categories of effort.

Category *A* includes also training in determining the costs of different methods of manufacture and in holding the product, once it can be made at all, within specified dimensions, operational performance and quality limits.

BROTHER TECHNOLOGIES

At this stage, the student and new engineer will need the broader view of Category *B*. He will need to know in quantitative terms the many incidental activities to be "geared in" with the basic ability to make reliably a good product. One such subject or activity is material handling. Others are the appraisal of wage plans and grading of labor skills, amount of machinery and floor space to be provided, the quantity of product to be made in one lot if it is not continuous production, estimation of future costs, and so on.

The absence of product design in this category may raise protests. It is not here because most Industrial Engineers will work, at least for the first few years, on making products they could not have designed. They should in those early years be able to understand and analyze the designer's sketches from a manufacturing standpoint to minimize cost and to improve the product. Later they may be called upon to take a more direct part in product design.

Category *B* somewhat hesitantly includes industrial organization as a distinct subject. Since first use of the term Industrial Engineer, it has signified people greatly

interested in the organization of human effort for various phases of production. Division of labor, transfer of skill, wage incentives, direct and indirect labor were terms much used in the early texts. The remainder of the texts were devoted to topics such as factory layout that now require books for suitable treatment. The profession's strong interest in the processes of manufacture made its preoccupation with the organization of direct labor inevitable. Extension of this interest into the organization of indirect labor and the best combinations of direct and indirect labor was not so inevitable. Had the study of economics been closer to industry, and had the schools of business shown their present interest in organization, quite probably the Industrial Engineering curricula would have tapered off sharply in the field of indirect labor and over-all organization.

Nevertheless, most Industrial Engineering curricula did retain an interest in organizational theory even though industry until recently showed rather little interest in it. In the last ten to fifteen years, industry has become acutely aware of all aspects of theories of organization from the bottom up and crosswise. Employers now seek Industrial Engineers for services in these fields where they formerly thought students were wasting their time or were getting an engineering degree the easy way. Fortunately, the early advocates of Industrial Engineering, certainly Taylor and some others, saw the importance of the organization of industry as a whole. Their publications and enthusiasm led teachers to leave it in the curriculum even though from about 1915 to 1940 little was added to its theoretical foundations, unless perhaps Western Electric's Hawthorne Experiments contributed to them.

COUSIN TECHNOLOGIES AND SUBJECTS

The subject of industrial organization appears again in Category *C* because its scope as there conceived extends beyond the basics of the early leaders, possibly even beyond their unexpressed concepts. It embraces communications, decision-making, organization for change, engineering administration, task forces, committee control, decentralization, feedback, computers, electronic data processing and rather little about "line and staff" organization. In this sense the subject of Industrial Engineering aims at the design and measurement of organization for industry, at its use to correlate all activities. These ideas or techniques with systems analysis, integrated data processing, operations research, and results measurement and control are becoming a common background. Some knowledge of their objectives and interrelations must be in the graduate's concept of industry if he is to carry on the more obvious technologies with confidence. For years and years of his career, especially in a large corporation, he may seem to make no impression on these aspects of organizing for industry. Nevertheless, the background of their study provides a sense of direction to his efforts.

In this same vein, operations research which appeared in Categories *A* and *B* also appears in *C*. This subject is new enough to permit a variety of definitions of its scope and promise. Its appearance throughout the curriculum aims to keep before the student the idea that his mathematics and pure science are tools in themselves and that the technologies of Industrial Engineering do not furnish the only tools to apply to industrial problems. If he takes the position that he can solve all problems in his field, he will make the serious mistake of impeding progress and foregoing the more elegant solutions that mathematicians, physicists, chemists, physiologists, electrical and machine designers and accountants can sometimes offer if he will but take the time to explain to them the situation and his concept of the problem.

Having gone this far with listings and categories, acknowledgment should be given to the undesirability, and even the impossibility, of maintaining all these subjects within distinct limits and of maintaining the categories in nice time compartments, either as to the experience of an individual engineer or as to the timing for instruction. One of the worst possible mistakes would be to do a fine job in several subjects of Category *A* without relating them to each other and industry as a whole with subjects from Categories *B* and *C*. From the standpoint of faculty organization, however, it could be quite satisfactory to select the subjects taught by one instructor entirely from one category.

RELATIVE IMPORTANCE

At this point, a distinction needs to be made as to the importance of the subjects in *A*, *B*, and *C*. In a large corporation, one can go through the organization and find individuals and perhaps departments whose work is limited to only one or another of the technical activities listed, let alone all the activities of one category. In fact, there may be several departments spending all their time in only one activity such as quality assurance. Many individuals make a very satisfactory lifetime career in only one activity, never engaging in overall administration. They are the real experts who formulate the respective technologies. Part of the fascination of small businesses stems from the probability that a capable young graduate soon after employment will be given responsibilities in several of the activities during the year's work. He will not become an expert at any of them, but then he will not have the struggle of a classmate who tries as a sideline to his regular job to get a picture of the business as a whole. This is not to say that the small business or the large business is better or worse for the graduate. There are enough temperaments and openings to go around. The trend, however, is toward greater specialization of activities, even in small businesses.

For faculties to imbue their students with such enthusiasm for administration that the graduate will accept only supervisory work, which usually is possible only in a small enterprise, is to deny him the opportunity to become competent, if not an expert, in one or more fields

before he thinks himself ready for administration. No group has a harder time finding employment than the graduates who for their first five years have ridden fast with broad responsibilities and wonderful salaries in unstable industries or industrial situations, then find they have been skimming the surface and must start again because most substantial employers want their employees to have specific abilities in well-defined fields during the first few years of their service.

After talking with candidates for graduate schools of business administration and with graduates of these schools, it is evident that the schools should drop the second word and become simply schools of business, letting "administration" take its place in the curriculum with the many other subjects that must be included. Departments of Industrial Engineering as well as students have been fascinated by this term administration. In fact, some narrowly missed adopting the name "industrial administration"—others have adopted it. As was said earlier, the interest that has been aroused in industry in communications, problems of change in product, personnel and practices encourages the Industrial Engineering, business and economics faculties to stress administration and creates a demand for their services as consultants in administration. These pressures can easily lead to neglect of the more scientifically founded subjects in student curricula, at least for Industrial Engineers. The student should be encouraged to believe that any of the subjects in the list is worthy of his best efforts and a career. In the face of frequent emphasis by many faculty members that high administrative responsibility measures the success of an engineer's education and career, more emphasis is needed that advancement of the theoretical foundations of and expert practice in any of the many areas of this branch of engineering, is a more accurate measure of professional contribution and success than administrative position.

CORE TECHNOLOGIES OF INDUSTRIAL ENGINEERING

Which then are the basic Industrial Engineering technologies? For the undergraduate, marketing, business law, business finance, and business administration can be eliminated. They will be needed later if at all, and can be acquired by observation, independent study, or night school and extension course study. If the remainder must be pared to the bone, it should include:

Process Analyzing and Planning
Quality Assurance
Dispatching, Scheduling and Programming
Cost Accounting
Industrial Organization
Results Measurement and Control
Operations Research

To cut off the others listed in the previous tabulation seems like taking all flesh off the bones and some of the bones as well. But many of the subjects like manufacturing equipment planning and design, factory layout, and materials handling will be picked up fast in actual practice by observation, association, and supplementary study.

If one assigns to each subject in the more complete list the underlying studies most used in the technology, it is revealing to see how often mathematics and mechanics appear. Little doubt can remain, if any did, about the caliber of the studies in the list. They are technologies in their own rights, so much so that an engineering course on a par with civil, electrical and mechanical engineering can be organized from them. The advantages which might result from putting such a course on a par administratively as compared with leaving it in mechanical engineering curricula might bear examination. Much is to be said for leaving it under mechanical engineering in any particular school until it takes firm and permanent root in the sciences and engineering and has achieved with its technologies a level of scholarliness equal to the level of the other engineering schools.

Quite appropriately some colleges should not attempt to offer a full curriculum in Industrial Engineering. Then the choice has to be made between offering a very few courses of high scholastic quality, or offering survey courses, the latter being given as a sideline to some teacher's major interest. From the tone of this article, it is apparent that the latter choice is undesirable and unworthy of the possibilities of the subject. Probably the minimum should be what one teacher spending full time in the field can offer. Lacking that, most night schools of college level in industrial areas are equipped to teach Industrial Engineering for those who cannot get it in their undergraduate curricula; some employers support a program of college work during working hours.

CONCLUSION

The scientific content of Industrial Engineering technologies increases rapidly. Much of industry is not organized to employ these technologies to best advantage and industry is uncertain whether its demand for students of these technologies is because of their engineering and scientific aptitudes or because of their immediate or future potential for administration. Some schools are having difficulty deciding first, whether the technologies should associate primarily with Industrial Engineering or with business curricula, and second, at what level the studies should be presented.

Nevertheless, industry's improving perception of production as a closed system, starting with need for a product and its design, and continuing through planned production, organization and control, to coordination of cost with profit and customer's needs, brings industry much closer to recognition of the concept most teachers of Industrial Engineering have taught since becoming intrigued with the ideas of Frederick Taylor.

Optimal Location of New Machines in Existing Plant Layouts

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THE PROBLEM considered here is the determination of the optimal location for a new piece of equipment in an established and fixed layout. Several measures of effectiveness are proposed and their appropriateness discussed under different conditions.

A limited amount of quantitative work has been done on this problem by earlier writers (1) (4) (5). In addition, the economists have also been working on a similar problem involving the location of economic activities such as manufacturing operations (2) (3). In each case, however, there were limitations which resulted either in restricted applicability or excessive computational effort.

MEASURE OF EFFECTIVENESS

In this proposal each point of a two-dimensional machine layout will be assigned a numerical value. This figure indicates the total material handling costs of all material flow to and from the new equipment if it were located at that particular point of the layout. At each point of the layout, there is one such value for each new machine to be added to the existing set of machines. It is assumed that cost considerations for determining optimal layouts are related in a linear manner to distance. This assumption has never been clearly proven nor disproven, however it is one that has been made repeatedly in layout work.

Let us first limit our discussion to the addition of a single new machine. In this case erch point of the layout has a single value indicating its effectiveness for locating the new machine. By connecting all points of the layout having one particular numerical value, a continuous line is obtained, an iso-cost line. This line is comparable to the constant elevation line found on contour maps and is sometimes called a level curve. Instead of representing elevation, the level curves in the layout problem represent material handling costs.

In many layout problems the arrangement of plant facilities is so closely allied with materials handling that a criterion of minimum material handling cost is used as a measure of effectiveness. Often this is not unreasonable. Numerical measurements of move-distances are comparatively easy to obtain and, to the extent that they represent material handling costs, can serve as quantitative evaluation for locating new equipment.

The physical distance between any two layout points can be measured in different ways, depending on the conditions imposed by the material handling systems used. Two particular models will be discussed here:

1. The "straight movement" case.
2. The "rectangular movement" case.

STRAIGHT MOVEMENT CASE

In the straight movement case, the measure of effectiveness of any point under consideration for locating the new equipment is defined as the sum of all straight-line distances between that point and the location of each existing machine. The use of this sum of distances as a measure of effectiveness requires that the following basic assumptions be fulfilled:

1. The material flow between any two machines follows the shortest possible path, i.e., the straight line connecting the two machines. If the handling of materials is done by conveyors, this simplification of the true situation seems reasonable. However, if the conveyors also perform processing or storage functions, or if materials are handled in palletized unit loads with fork trucks, this assumption cannot be made without further investigation.

2. The material handling costs per unit of distance are the same between the new machine and each one of the existing machines receiving materials from, or supplying materials to, the new machine. This is true if the handling costs do not vary with the volume handled. Otherwise, equal volume of material flow must be assumed.

Comparative costs of alternative materials handling methods are not generally available as yet. Hence, there is difficulty in properly evaluating alternative handling media by this method. However, the objections to this assumption can be partially overcome by weighting schemes to be introduced later.

3. Materials handling costs are directly proportional to the distance moved. Although initial cost, operating cost and maintenance cost definitely increase with the distance over which the materials move, little is known about the behavior of these costs as functions of the distance, particularly in cases where several material handling systems could be used or where the distances involved vary within very wide ranges.

STRAIGHT MOVEMENT—SPECIAL CASES

In the simplest case, a new machine is to be added to a layout involving only one existing machine. If the location of the latter is used as origin for the coordinate system, the measure of effectiveness M of a point (x, y) is:

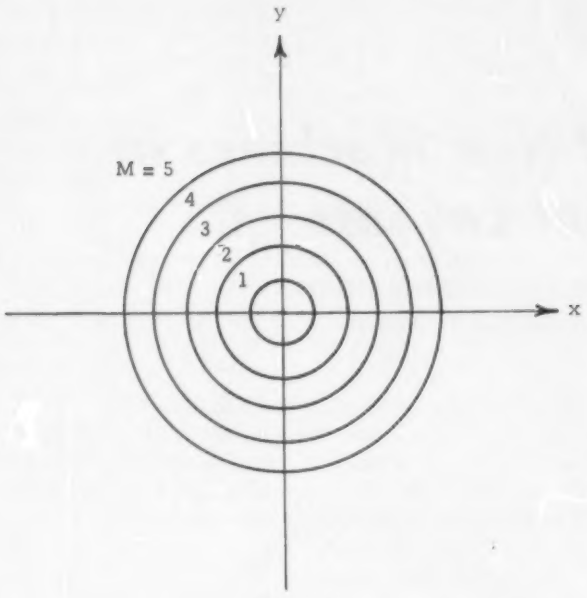


FIGURE 1

$$M = \left| \sqrt{x^2 + y^2} \right| \qquad \text{Eq. 1.}$$

The level curves in this case, represented in Figure 1, are concentric circles centered at the location of the existing machine. The best location for the new machine is the one already taken by the present machine. The further away from this location, the greater the measure of effectiveness and thus the less desirable the location.

If the existing layout has two machines located at $(-d, 0)$ and $(d, 0)$, the measure of effectiveness M of a point (x, y) becomes:

$$M = \left| \sqrt{(d+x)^2 + y^2} \right| + \left| \sqrt{(d-x)^2 + y^2} \right| \qquad \text{Eq. 2.}$$

The resulting level curves are confocal ellipses with foci located at the two existing machines, as shown in Figure 2. The optimal location for the new machine in this case is any point of the segment delimited by the two existing machines ($|x| \leq d$, $y = 0$) for which $M = 2d$.

A more general statement of the measure of effectiveness for two existing machines located at (x_1, y_1) and (x_2, y_2) is as follows:

$$M = \sum_{i=1}^{2} \left| \sqrt{(x - x_i)^2 + (y - y_i)^2} \right| \qquad \text{Eq. 3.}$$

Similarly, with n existing machines located at (x_1, y_1), (x_2, y_2), $\cdots$, (x_n, y_n),

$$M = \sum_{i=1}^{n} \left| \sqrt{(x - x_i)^2 + (y - y_i)^2} \right| \qquad \text{Eq. 4.}$$

Consider, for example, the following problem. A new piece of machinery must be optimally located in an existing layout involving four machines. The new machine will send or receive approximately equal amounts of material to or from each machine already in use in the plant. These four machines are quite large and it is therefore felt that moving them is not economically feasible. They are located at (0, 0), (1, 2), (2, 4) and (6, 1). It is anticipated that belt conveyors will be used to handle materials between operations. The level curves for this situation are shown on Figure 3.

The graphical solution becomes more involved as the problem becomes more realistic. However, in a practical problem, a complete set of level curves is not necessary for determining a satisfactory solution. Plant conditions often reduce the number of available potential locations to a small figure so that selected level curve segments can furnish all information necessary for making a decision. Another method for selecting an optimal location is to calculate and enumerate the M value for each of the candidate areas available. If, for example, in our illustration of Figure 3 we have the shaded candidate areas A, B, C, D and E, the calculation of representative M values for one or two level curves will indicate that area C is by far the best, area D second best and that area A and E are about equally desirable.

In situations where candidate areas are of equal or approximately equal value, the decision must be based on other factors and considerations which are not included in the calculation of the measure of effectiveness, such as accessability, floor carrying capacity and service connections. A certain amount of intuitive correction will be necessary in all cases before making a final decision in order to insure the proper weighting of all factors to be considered, whether or not they have been included in the measure of effectiveness.

The best location can be determined analytically by taking the partial differentials of the expression for M in

(Continued on page 43)

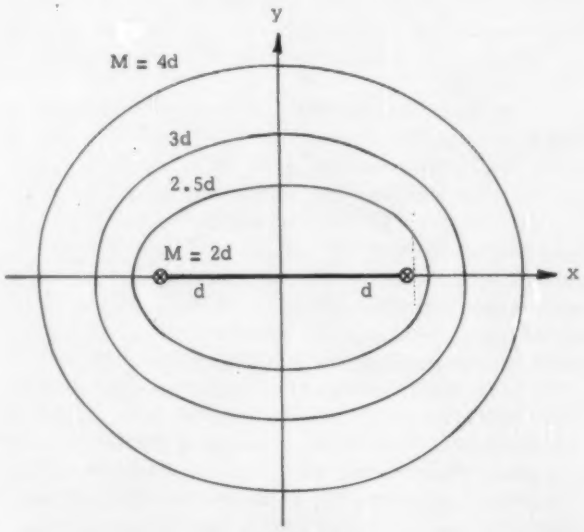


FIGURE 2

INSTITUTE INTERESTS

A new method of presenting Institute Interests is being initiated with this issue. Our objective is to assemble and edit interesting highlights of both local and national events. You, as individuals, chapters, or national functions, are encouraged to become primary reporters. Please send interesting news items directly to Professor Wilson J. Bentley, School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma. If you forget this address, send it to the Journal *in Atlanta, and that office will forward it.*

A starting list of subjects for inclusion in this section has been drafted. As suggestions occur to you, please send them to us.

1. *Short articles (or abstracts of long articles) which are not usually selected for the* Journal, *but which are of interest to* Journal *readers.*
2. *Industry and Community Interests.*
3. *Student chapter news and significant activities.*
4. *University and college news and activities.*
5. *Industry-university cooperative activities in Industrial Engineering, such as fellowships, donation of equipment, projects, etc.*
6. *Conferences, institutes, seminar dates and places.*
7. *Foreign activities.*
8. *Professional engineering activities including NSPE, EJC and others.*
9. *"Personality" sketches of outstanding national and regional Industrial Engineers.*
10. *Allied professional activities.*
11. *Pictures to accompany above items.*

—Editor.

AIIE GENERAL NEWS

All members should have received a questionnaire designed to obtain information essential for the further development of the Institute, its programs and activities. The completed questionnaires were due back by December 5, 1960, and will provide information of interest to all Industrial Engineers.

President Alex Rathe's activities at the "half-way" mark have included a get-together with 25 Chapters in 17 Chapter meetings and 16 informal sessions with the Chapter Officers. This provided the opportunity for him to meet nearly 300 local officers and some 1,500 members on trips totaling 12,500 miles.

The Executive Committee reaffirmed, at its November meeting, AIIE's policy of long standing against the possibility of membership in AIIE by a company as such. The Trustees took this stand unanimously upon the strength of recommendations developed by the Membership Board of Review, under the chairmanship of Bill Fourqurean, in another thorough study of the problem.

Region IX has recently installed Chapter 109 which is the "Great Plains" Chapter located at Lubbock, Texas.

STUDENT CHAPTERS

The student chapter at the University of Arkansas has been designated the Outstanding Student Chapter for 1959. The Southwest Student Chapter Chairman, Dr. Richard A. Dudek, made the presentation on December 21.

Texas Tech's student chapter of the AIIE sponsored an official school field trip to Chihuahua, Mexico in late November. The purpose of this field trip was to tour the industrial installations located there and to see applications of Industrial Engineering that were conceived by German, Japanese, and American engineers. These industries include:

1. $75 million paper manufacturing plant.
2. An integrated system of two textile mills and a clothing manufacturer.
3. The American Mining and Smelter Plant.
4. A large steel fabrication plant.
5. The second largest beverage manufacturer in Mexico.
6. And, several other plants.

The city of Chihuahua is located approximately 280 miles south of El Paso. It has a population of around 122,000 people, and is one of the industrial centers of Mexico. Personal invitations from all of the industries to tour their facilities were extended. The trip was made by bus from Lubbock, Texas, to El Paso. After being assisted through customs by Chihuahua's Chamber of Industrial Organizations, the group continued by train to Chihuahua. Dr. Dudek accompanied the students.

Oklahoma State University's student chapter reports an active membership. Included are: Stanley Jones elected to membership of the Blue Key, a national men's honor society. Ray Asfahl and Dale Farquharson were listed in *Who's Who in American Colleges*. Other honors by membership of the Chapter: Fifteen members initiated into Alpha Pi Mu, eleven members are in Engineering Toastmasters, five members are in Sigma Tau (engineering honorary), seven members are on the *Oklahoma State Engineer* (the engineering magazine on campus) staff, and four members are on the engineering student council.

The Boston Chapter was host to a successful Region I Con-

Mayor John F. Collins seated, presenting to Alfred Pace, president of Boston Chapter, American Institute of Industrial Engineers, a Proclamation declaring November 3rd and 4th to be Industrial Engineering Days in the city of Boston. Standing left to right, William Vallette, Director of Industrial Engineering, CBS Electronics, Theodore Ulman, Raytheon, and Herbert Margoshes, Sylvania, all Boston Chapter officers. The Boston Chapter is host for this year's Regional Conference and Convention at the Sheraton-Plaza.

ference held at the Sheraton Plaza Hotel on Thursday and Friday, November 3, 4, 1960. The theme: "Industrial Engineering Today, the Gateway Tomorrow," was capably covered by such well-known speakers as Mr. Jerome Barnum, Jerome Barnum Associates, Scarsdale, New York, Dr. Kenneth McFarland, Education Consultant, General Motors, Dr. Robert N. Lehrer, Chairman, Department of Industrial Engineering, Northwestern University, Dr. Andrew Schultz, Chairman, Department of Industrial Engineering, Cornell University, and many others. The well over two hundred Industrial Engineers who attended were highly complimentary concerning the high caliber technical content of the program, the chief Industrial Engineers forum, and the exhibits.

Accompanying the Region I Conference was a meeting of the National Executive Committee as well as a business meeting of Region I Chapter Presidents and Officers.

INDUSTRIAL ENGINEERING AND INDUSTRIAL ENGINEERS IN INDUSTRY

Procter and Gamble is training "Fleet Work Study Groups." The first group designated as Fleet Work Study Group—Atlantic, consisting of four Naval Officers and eight enlisted men, was trained by the Industrial Engineering Division with local plant participation, during January-March, 1960. After completing a course at the Royal Navy Work Study School, they began operations at Norfolk, Virginia, on May 1, 1960. A similar group, designated as Fleet Work Study Group—Pacific, was trained by the Industrial Engineering Department of the Long Beach Plant, and began operations at San Diego, California, on July 1.

During their eight-week training period, each group was given basic instruction in Industrial Engineering and an opportunity to practice plant applications. Both groups approached their training assignments enthusiastically and completed their training well qualified to identify, develop, and initiate cost reduction projects and programs in the Fleet Operations of the Navy.

A further extension of this function within the Fleet, will be dependent on the achievements of these two pilot groups.

NELSON K. ROGERS

Nelson K. Rogers, who helped design the first modern trailerships, and Michael R. McEvoy who helped to promote them, have been made vice presidents of Sea-Land Services, Inc.

Mr. Rogers is presidential assistant responsible for marine operations as well as for future operational design and development. Mr. McEvoy was named general sales manager earlier this year.

It was in 1956, when Mr. McLean had begun hauling trailer bodies atop decked-over coastal tankers, that Mr. Rogers, as research engineer in Mobile, Alabama, began a two-year task of helping to design the present automated van ships and ship vans.

He has served as associate editor of *The Journal of Industrial Engineering*, and formerly taught Industrial Engineering at Georgia Institute of Technology, Atlanta, from which he holds a master's degree. He has been president of the Mobile Chapter and secretary of the Atlanta Chapter of the American Institute of Industrial Engineers, and is a member of marine, electrical and other engineering societies.

A native New Yorker and resident of Chatham, New Jersey, Mr. Rogers is a graduate of the U. S. Naval Academy at Annapolis. As a naval lieutenant on command duty, he saw active service in Korea.

Mr. McEvoy, also a Chatham resident, was for many years a city editor and columnist on newspapers of his native Mobile, Alabama. There along with Mr. Rogers, he joined the McLean shipping interests in 1956 and organized the first promotional program for trailershipping, later headquartered in Newark.

David J. Bender has been named Chief Industrial Engineer for the Johns-Manville Fiber Glass Division. He will headquarter at division general offices in Toledo and will supervise all Industrial Engineering for the firm's seven manufacturing plants in the United States.

Mr. Bender entered the glass industry in 1952 when he joined Glass Fibers, Inc., a predecessor firm, as an Industrial Engineer. Later, he was made engineering supervisor of the Defiance, Ohio plants and held that position when Glass Fibers, Inc. became L.O.F. Glass Fibers in 1955. He was named packaging and material handling engineer in 1956 and continued in that capacity after the company was acquired by Johns-Manville in 1958.

Prior to his glass experience, Mr. Bender was with Fuller Brush Company, Toledo Liner Company, and Toledo Terminal Railroad.

Richard E. Garner has been appointed superintendent of the Industrial Engineering Department at Kaiser Steel's Fontana, California plant.

Garner joined Kaiser Steel in 1952 as a junior Industrial Engineer. He advanced to Industrial Engineer, senior Industrial Engineer, supervisor, and assumed a division responsibility in 1959, the position he held until his present appointment.

The new superintendent is a member of American Institute of Industrial Engineers, American Material Handling Society, Association of Iron and Steel Engineers, and is a lieutenant commander, United States Naval Reserve, Los Alamitos.

INTERNATIONAL ACTIVITIES

The Council for International Progress in Management announced a contest for a paper on "Scientific Management and Its Responsibility for Bettering the Standards of Living in the Americas," held under the auspices of the Council's Mexican counterpart, the Confederación Patronal de la República Mexicana. Papers may be of any length and must be sent in duplicate to the Confederación Patronal de la República Mexicana, San Juan de Letrán 13, México 1, D.F., México, no later than January 15, 1961.

First prize is 15,000 pesos (at present exchange, approximately $1,200), a gold medal and a diploma. Second prize is 10,000 pesos (at present exchange, approximately $800), a gold medal and a diploma. Third prize is a gold medal and a diploma.

The Confederación Patronal, a Mexican management association is holding the contest in conjunction with the Third Inter-American Management Conference which will take place in Mexico City, March 6-11, 1961, under the Confederación's direc-

tion. Representatives of industry, consulting firms, and universities from all the Americas will meet at this Conference to hear papers on topics of mutual concern in the management field and to exchange ideas and experiences. The Conference is held under the auspices of the Pan American Council of the Comité International de l'Organisation Scientifique, an international management body with member associations in eight countries of the Western Hemisphere.

UNIVERSITIES AND COLLEGES

Professor Albert Rubenstein of Northwestern University's Department of Industrial Engineering, has received a grant from the McKinsey Foundation permitting him to continue his research on "Organization of Research and Development in Decentralized Companies." Starting four years ago, he has been analyzing the impact of organizational decentralization on large companies. Impact of decentralization on research results is a special goal of the study, which involves more than 100 companies.

Bruce M. Johnson, at Northwestern University, is a new Assistant Professor of Industrial Engineering, specializing in the field of operations research. He is a candidate for the doctorate in this field from Cornell University. In his dissertation, Johnson and two co-workers have evaluated the scheduling of a job shop, and developed a mathematical model of the operation; this enables them to plan more efficient use of the plant's equipment and men.

C. M. Shetty also has been named Assistant Professor of Industrial Engineering at Northwestern. Last spring, Shetty received the annual Graduate Student Prize of the American Institute of Industrial Engineers for his work on "sensitivity analysis" in linear programming. A native of India, he came to the United States on a Fulbright Fellowship to study Industrial Engineering.

The Johns Hopkins University School of Engineering has consolidated its departments of aeronautics, civil engineering, and mechanical engineering into a single unit to be known as the Department of Mechanics.

The announcement was made by Milton S. Eisenhower, President of The Johns Hopkins University, and Robert H. Roy, Dean of the School of Engineering.

The action creating the new department was taken on the initiative of the faculties of the departments concerned, Dean Roy explained, and with the approval of the Advisory Board of the School, the Visiting Committee of the School of Engineering and the administration and trustees of the University.

The new action now leaves the School of Engineering with departments of chemical, electrical, industrial, and sanitary engineering, along with the new department of mechanics.

PROFESSIONAL NEWS

United Engineering Trustees, Inc., an organization of five major national engineering societies, has announced at its headquarters in New York City, the election of Willis F. Thompson, of New Haven, Connecticut, as President.

Mr. Thompson, who is Executive Vice President of Westcott and Mapes, Inc., of New Haven and a former Vice President of The American Society of Mechanical Engineers, succeeds Andrew Fletcher, of New York, Chairman of the Board of Directors of St. Joseph Lead Company, and former President of the American Institute of Mining, Metallurgical and Petroleum Engineers.

Mr. Thompson and Mr. Fletcher are exchanging posts. Heretofore, Mr. Thompson has been Chairman of the UET Real Estate Committee, a function now undertaken by Mr. Fletcher. For the past several years, both have been driving forces in the program resulting in the new United Engineering Center, a $12,000,000, 20-story structure at United Nations Plaza at 47th Street, in the United Nations area, scheduled to open the latter half of 1961. It will house the world's largest assembly of professional engineering societies.

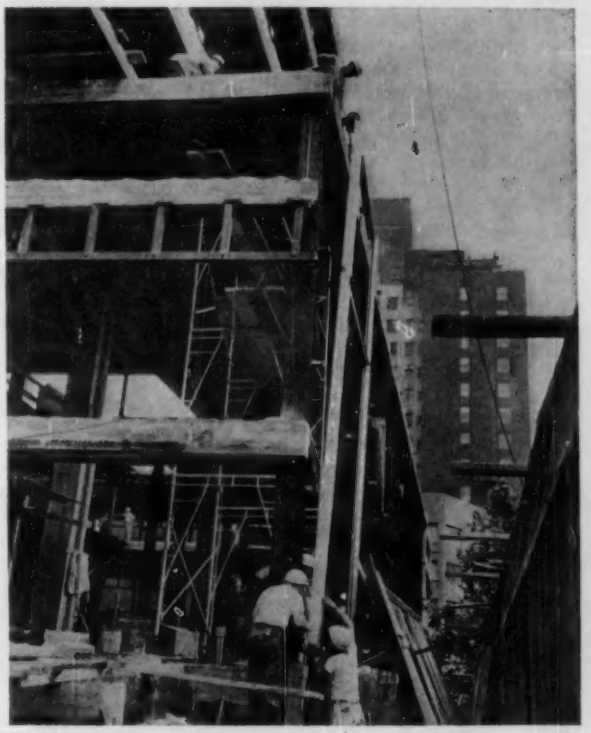
UET announced, also, the election of two new Vice Presidents and two new members of the Board of Trustees. The new UET Vice Presidents are James F. Fairman, of New York, Senior Vice President of Consolidated Edison Company of New York, representing the American Institute of Electrical Engineers, and L. C. Kemp, Jr., of New York, Vice President of Texaco, Inc., representing the American Institute of Chemical Engineers.

The new trustees are Michael L. Haider, of New York, Vice President and Director, Standard Oil Company of New Jersey, representing the American Institute of Mining, Metallurgical, and Petroleum Engineers, and William H. Wisely, of New York, Executive Secretary of the American Society of Civil Engineers.

This year's large increase in the use of the Engineering Societies Library, reported by its director Ralph H. Phelps, indicates a continually growing awareness of the library's value to the engineering profession. Orders received by mail from individuals and companies all over the world, for services such as literature searching, translating, and photoprint and microfilm copying, increased 25% over last year. Requests received by telephone increased over 35%. Such non-visitor use now is 68% of total library use.

UET is a non-profit organization consisting of five "Founder Societies." They are the American Society of Civil Engineers, the American Institute of Mining, Metallurgical, and Petroleum Engineers, The American Society of Mechanical Engineers, the American Institute of Electrical Engineers, and the American Institute of Chemical Engineers.

UET was created in 1904 following a gift by Andrew Carnegie



Stainless steel window grids for the glass-walled east base of the United Engineering Center are lifted into position. A display area of 6,235 sq. ft. will be enclosed by the wall. This is the first of some 170,000 pounds of stainless steel that will provide beauty and durability to the skyscraper's exterior.

Construction is being financed by gifts from industry and individual engineers, plus other assets of the United Engineering Trustees, including sale of the outgrown Engineering Societies Building on 39 Street in New York City.

for an engineering center for "the advancement of the engineering arts and sciences in all their branches, and to maintain a free public engineering library."

UET owns the 16 story Engineering Societies Building at 25-33 West 39th Street, Manhattan, as well as being the owner, too, of the new United Engineering Center now under construction, ground for which was broken by Herbert Hoover. UET sponsors the awards of the famous John Frits and Daniel Guggenheim medals. It includes, as departments, the Engineering Foundation and the Engineering Societies Library.

RESEARCH ACTIVITIES INVOLVING INDUSTRIAL ENGINEERS

The Medical Care Research Center, established earlier this year as a joint venture of the Social Science Institute of Washington University and Jewish Hospital, has been awarded a five-year $564,518 United States Public Health Service grant.

Co-investigators of the research program are Dr. David Littauer, Executive Director, Jewish Hospital, and Dr. Nicholas J. Demerath, Director, Washington University Social Science Institute.

The Center will encourage cooperative research activities by professional medical and administrative persons and social scientists in studies of the organization and administration of health services in the general hospital and the community. Involved in studies will be sociologists, Industrial Engineers, cost accountants, medical economists, psychologists, physicians, nurses, and hospital administrators. Ultimate objective is to find the best types of patient care at the lowest possible cost.

Both short and long-term studies will be conducted in the Center under the supervision of project directors representing specialty areas in the social sciences and medical administration.

Project directors will include Dr. Gerald Nadler, Chairman, Washington University Department of Industrial Engineering, Dr. Alvin W. Gouldner, Chairman, Washington University Department of Sociology-Anthropology, Dr. Burton Weisbrod, Assistant Professor of Economics, Dr. Jay Goldman, Assistant Professor of Industrial Engineering, Mr. David A. Gee, Associate Director, Jewish Hospital, and Dr. Albert F. Wessen, Assistant Professor of Sociology and Psychiatry at the University and Medical Sociologist at the Hospital. Dr. Wessen is also Executive Director of the Center.

Research persons in the Center will explore medical care programs and their organization both in hospitals and similar community institutions.

The Center will also examine the role of separate medical care units or programs, such as chronic disease, rehabilitation or psychiatric units, in one institution. The influence of units on each other will be studied to determine how each unit affects the overall policies of the institution.

Other research efforts will deal with methods to make medical care organization more efficient and less expensive. Costs of patient care and factors determining costs will be studied. Researchers will also design new methods for providing health care and attempt to improve existing methods.

Several studies are already underway at the Center. One of the most extensive involves the application of "Work Design to Nursing Activities" to determine if certain time-consuming activities of all nursing personnel can be replaced by simpler, more effective procedures which will release nurses for more essential tasks. The project team, including Industrial Engineers, nurse, sociologist, and hospital administrator, is getting ready to test a new medication administration system which represents a radical departure, with great savings of time, from past practices, and promises to be applicable to any hospital. Another current study includes a survey of organized home care services for the chronically ill, using the Jewish Hospital program as a study base.

Just completed is a study on the use of simplified equipment that will deliver hot food to patients' rooms while utilizing fewer dietary workers.

Graduate students from the social sciences, Industrial Engineering, hospital administration, and medicine will be part-time research assistants at the Center. Seminars are being held to discuss research problems and results with medical care groups elsewhere. Visiting professorships may be appointed from time to time at the Center.

COMMUNITY SERVICES

The following is an article submitted by Henry E. Thomson, Chairman, Community Services Committee, 1960-61. He entitles it, "Chapter Community Services—A Challenge and an Opportunity"—Editor.

Industrial Engineers have long recognized that their professional status entails certain community obligations. Many chapters of the American Institute of Industrial Engineers have done excellent work in furnishing Industrial Engineering community services to various public or civic non-profit organizations. In so doing they have paved the way for even greater and better contributions in the future. However, their light has been hidden under a bushel. Other chapters which could and should provide such services have not yet gotten off the ground. They need to know the lessons learned by those who have pioneered in this activity. However, not until this year has a community services program been established on an Institute-wide scale. Last May the Community Services Committee became one of the Institute's family of seven work committees reporting to the Executive Vice President.

In addition to guidance information and program stimulation, the Committee is charged with leadership in formulating an Institute policy for adherence to acceptable standards of chapter and individual performance. This is not to be a rigid code or straight-jacket that would restrict or hamper originality and ingenuity. Instead it should afford necessary means for central control over only those aspects of the program that involve Institute support and sponsorship for chapter community services programs. To develop wisely such an Institute policy will challenge the best minds and most experienced members of AIIE—as well as Committee Members who are now at work on this problem. Such a policy might well include naming types of organizations deemed eligible for chapter Industrial Engineering assistance; safeguards against involvement in partisan politics or in areas legitimately open to the enterprise of professional consultants; insistence upon sufficient client-participation to assure that services will be mutually beneficial; and that such ventures be adequately planned with publicity sought only after tangible progress is evidenced. Although monetary fees are not to be a consideration, we should not be offering something for nothing. In return for its assistance each chapter should expect such an investment of the client's time and effort as to make the experience a rewarding one for the individual Industrial Engineer or Industrial Engineering team. Also, such participation is most likely to assure expeditious completion of the project. Solicitation, of course, must always be conducted on a purely professional level.

The Institute's Community Services Committee is decentralizing its operations through the Committee Member established on the Regional Vice President's staff in each region. He actively assists by receiving and distributing guidance material; by consulting with Chapter Presidents and their local community services committees; and by maintaining at all times complete liaison with his Regional Vice President. Regional Vice Presidents and Chapter Presidents are assured that this program is no more than an offer of assistance to them—that in no manner will the Institute's Committee dictate how they may best derive maximum benefits from their implementation of the program. Liaison is also main-

tained with Public Relations and Chapter Development Committees on both Institute and regional levels. Names and addresses of Community Services Committee Members are:

Region	*Member*	*Chapter*	*Address*
I	Jeremy E. Johnson	97	Scovill Mfg. Co., 99 Mill Street Waterbury 20, Connecticut
II	Charles F. Stephenson	72	225 East Market Street York, Pennsylvania
III	Douglas T. Watts	21	2735 Melinda Drive Winston-Salem, North Carolina
IV	William E. Dykes	6	110 Normandy Drive Marietta, Georgia
V	Raymond G. Cooper	51	1341 West 10th Street Erie, Pennsylvania
VI	Willis G. Holder	2	4170 Beechwood Drive Bellbrook, Ohio
VII	Bert Greenglass	69	2913 Bayless Drive Huntsville, Alabama
VIII	Glenn D. Wolfe	45	A. O. Smith Corporation Milwaukee 1, Wisconsin
IX	Arthur L. Ziegelmeyer, Jr.	10	2900 Gardenia Drive Fort Worth 19, Texas
X	Donald F. Hydrick	29	8966 Cliffridge Avenue La Jolla, California
	James Lissner Assistant Chairman	20	3845 East 98th Street Seattle 15, Washington
	Henry E. Thomson Chairman	20	6533 17th Avenue, N. E. Seattle 15, Washington

Guidance material is sought through Committee Members, not only from chapters which have had successful experiences in providing community services, but also from all other fruitful sources. From such material, Guidance Sheets are published and distributed to all chapters for their assistance and stimulation. Chapters are urged to supply committee members in their respective regions accounts of specific approaches and methodology employed in projects they have accomplished. It is not enough to record *what* was accomplished. Each account should describe in detail every key step taken, from project initiation to completion and follow-up, including *how* and *why* success was achieved.

A notable example of a useable report is the excellent account of services rendered the Jewish Vocational Center by Milwaukee Chapter. Three years ago Marquette University approached the Chapter for assistance to the Center in its programs for rehabilitation of handicapped persons. Led by senior and retired Industrial Engineers, the Chapter's Community Services Committee aided the Center on long-range plans, shop and maintenance problems, established a production control system, educated supervisors in work simplification and management engineering, and publicised this work—after the program had become fully seasoned. A conveyor belt was installed and work layouts designed to facilitate maximum value therefrom. The therapeutic value and competitive spirit engendered to become a worker on "the belt" was so great that poor workers strained to qualify. The Committee soon became involved in nut, screw and bolt counting, toy assembly, and manufacturing problems. A retired engineer designed a novel screw-counting machine that was patented on behalf of the Center. Lighting, layout and maintenance were gradually improved.

The Jewish Vocational Center manufactures two items: one a place mat of thermoplastic pellets for which the Committee specified type, size, purchase and installation of materials and equipment; the other, a new item, consists of headboards for Hollywood beds as specified by a wholesaler. The first item is growing daily and is a good moneymaker. The Committee's work is enabling the Center to expand from 30,000 to 70,000 square feet and to include programs for juvenile delinquents and aged persons.

Lessons learned from this venture were: by starting slowly but thoroughly they didn't expect acceptance until value and worth had been demonstrated. This meant proceeding through all steps of job analysis, processing, planning, fixture design, construction and demonstration—and the task of educating the Center's staff to think and understand in terms of an Industrial Engineering approach. The feature that most taxed the Committee's imagination was that the desire to mechanize couldn't be realized without eliminating the human effort necessary for its therapeutic value in such an enterprise. They found they could eliminate wasted motion but not the worker. However, by increasing the scope and variety of manufacture and using profits for expanded capacity, they increased productivity and added *more* workers. This is a problem that has hampered other chapters which, lacking resources as flexible as in this case, could not install Industrial Engineering practices without displacing the workers—for whose rehabilitation more work had to be sought, instead of less.

Many other chapters have rendered effective community services to schools and school districts, Salvation Army, Community Chests, Heart Associations, hospitals, Urban Leagues, Family Service Associations, credit unions, Junior Achievement groups, Braille Institutes, homes for the aged, Boy Scouts, Girl Scouts, the Y.M.C.A., science fairs and chambers of commerce—but have not yet contributed much light on *how* such successes were achieved. The Committee Member in each region is anxious to receive the success stories from all chapters able to contribute, so that their experiences and lessons learned may be passed on to other chapters—thus enabling them to benefit by such an exchange.

By the end of the year the best material collected from chapters will be edited and consolidated in a Chapter Community Services Manual, together with other aids, policy statements, standards of performance, reports of results achieved and any other useful information that can be gathered. This Manual will be published by AIIE and distributed to each Chapter Community Services Committee.

During this first year the Community Services Committee must feel its way, plan, organize, grow and even profit by its own mistakes, to the end that its program may become increasingly valuable to the regions and chapters which it strives to serve. In order to fully accomplish this the Committee seeks and welcomes suggestions and advice from all AIIE members.

The Institute's Community Services Program is a challenge to chapters everywhere—and an opportunity to discharge community obligations inherent in the Industrial Engineer's dedication to—and enjoyment of—his professional stature.

ENGINEERS JOINT COUNCIL

James N. Landis, Vice President of the Bechtel Corporation of San Francisco, has been elected President of Engineers Joint Council at a meeting of the Council's Board of Directors.

Landis, who is past president and present Council member of the American Society of Mechanical Engineers, succeeds Augustus B. Kinzel, Vice President of Union Carbide, who headed EJC for the past year.

The Board re-elected George E. Holbrook as Vice President. Holbrook, past president of the American Institute of Chemical Engineers and present Vice President of E. I. du Pont de Nemours and Company, served in that post during 1960.

A study is to be undertaken with the financial assistance of the Engineering Foundation Board of the possibility of forming a National Academy of Engineering.

A committee will be appointed by the EJC President with the purpose of developing plans for a Museum of Science and Engineering which might be national in scope, and there may be a possibility of tieing this project in with the 1964 World's Fair.

Dr. Holbrook, in his capacity as Chairman of the Planning

Committee, announced the proposed formation of a Technical Co-ordinating Committee. It would consist of top men from each of the societies qualified to speak for their societies on matters pertaining to possible duplication of effort or interest between societies. This is one more attempt to improve communications between societies and help define areas of specific interest.

GREAT SALT LAKE CHAPTER NUMBER 50

The 1960 Western Regional Conference of AIIE was hosted by the Great Salt Lake Chapter on September 30-October 1, 1960 in Salt Lake City, Utah. Built around the theme "Concepts to Meet the Challenge of Modern Management," the Conference was attended by approximately 250 Engineers, Line Supervisors, Plant Managers, etc.

From left to right, the committee members of the 1960 Western Regional Conference are: Earl M. Frizzell, George E. Molascon, Don G. Giacomo, Charles R. Allcott, Robert N. Pratt, James J. Pinegar, Harry D. McTague, Chairman, Eleroy H. West.

The sessions of the Conference emphasized the requirements that all levels of today's management organizations must employ many and varied techniques to realize adequate returns on investment. Toward attainment of this goal, the Industrial Engineering profession stands ready to assist the management of any company, regardless of size, in achieving their profit goal by keeping abreast of the trends in the mathematical, physical, and social sciences.

Featured speakers were: J. E. Angle, United States Steel Corporation; A. W. Barkson, International Business Machines Corporation; C. E. Fitton, Jr., Thiokol Chemical Corporation; R. E. Garner, Kaiser Steel Corporation; Prof. William Gomberg, University of Pennsylvania; J. D. Hromi, United States Steel Corporation; William Jacko, United Steelworkers of America; J. B. Joynt, New York Central Railroad; D. S. Keogh, Jr., American Associated Consultants; W. R. Mellin, United Air Lines; R. G. Odom, General Electric; Dr. Alex W. Rathe, National President, AIIE; M. B. Skousen, Private Consultant; Dr. H. S. Taylor, Brigham Young University.

Also included as part of the Conference was a full ladies program sponsored by the Chapter Ladies Auxiliary, and featured Frank J. Johnson, Immediate Past President, AIIE as the speaker at a coffee hour.

Among the highlights of the Conference was a "command performance" of the world famous Mormon Tabernacle Organ featuring Alexander Schreiner at the keyboard. This performance was especially arranged for members of the National Executive Committee, AIIE who attended the Conference and other out-of-state visitor attendees.

WINSTON-SALEM CHAPTER SPONSORS SEMINAR

About 60 teachers and counselors from Winston-Salem and Forsyth County Schools attended the Seminar on Education and Careers in Science and Engineering here yesterday.

The seminar, held at the YWCA, was sponsored by the Winston-Salem chapter of the American Institute of Industrial Engineers, with the cooperation of city and county school officials.

Dr. R. G. Carson, director of instruction at North Carolina State College, described how teachers and counselors can help high school students properly choose a career in science or engineering. He said it was important to match a student's talents with his goals.

Dr. Carson said mathematics and science are important. He said it has been found that the student who has a "tinkering" interest in laboratory work is not necessarily good material for science or engineering.

HOW TEACHERS CAN HELP

Dr. Otto Meier, Jr., of the department of electrical engineering at Duke University spoke on how teachers and counselors can help students prepare academically for engineering or science careers.

Mr. J. S. Swajkoski, a member of the engineering relations staff at Western Electric Company, told what industry expects from the engineer. He said Western Electric, when it hires a new engineer, tries to determine his academic grades and considers his recommendations and experience. A yearly analysis is conducted of the engineer's work, including his production and creativity.

NEW HAWAIIAN CHAPTER IS CHARTERED

The first chapter of the American Institute of Industrial Engineers in Hawaii was presented its provisional charter during the past summer by Vice President Merle C. Nutt. Dr. Nutt reports an excellent group of Industrial Engineers forming the chapter. He planned to fly back to Hawaii in December to present the chapter with its regular charter.

Dr. Merle C. Nutt, Vice President of Region X of AIIE presenting the charter to the new President of the Hawaii Chapter 108, Stephen A. Reed, Jr., at the chartering party held at the beautiful Hilo Yacht Club on the island of Hawaii.

Those at the table reading from left to right around the table are: Dr. Merle C. Nutt, Vice President Region X, AIIE, Professor of Engineering, Arizona State University; Stephen A. Reed, Jr., new President Hawaii Chapter, Industrial Engineer, C. Brewer and Company, Limited, Hilo, Hawaii; Adam F. Scott, Industrial Engineer, Kohala Sugar Company, Kohala, Hawaii; James P. Hogan, Industrial Engineer, C. Brewer and Company, Limited, Hilo, Hawaii; W. Virgil Hendricks, Senior Industrial Engineer, Onomea Sugar Company, Papaikou, Hawaii; Edward L. Baker, Industrial Engineering Trainee, C. Brewer and Company, Limited, Hilo, Hawaii; Douglas M. Felix, Industrial Engineering Trainee, C. Brewer and Company, Limited, Hilo, Hawaii; Clinton W. H. Chock, Industrial Engineer, Hakalau Sugar Company, Hakalau, Hawaii; Daniel J. Canty, Jr., Vice President for Industrial Engineering, C. Brewer and Company, Limited; R. J. Winans, Industrial Engineer, Pepeekeo Sugar Company, Pepeekeo, Hawaii; Roy E. Ward, Methods Engineer, Puna Sugar Company, Olaa, Hawaii; Robert S. Anderson, Cultivation Superintendent, Pepeekeo Sugar Company, Pepeekeo, Hawaii; Fusayoshi Kawachi, Industrial Engineering Assistant, Hawaiian Agricultural Company, Pahala, Hawaii; Hugh R. Opperman, Industrial Engineer, Hutchinson Sugar Company, Limited, Naalehu, Kau, Hawaii; James W. Godfrey, Jr., Junior Industrial Engineer, Paauhau, Hawaii. They have signed up five additional charter members since this picture was taken and are off to a fine start.

POSITION CLASSIFICATION FOR INDUSTRIAL ENGINEERS IN CIVIL SERVICE

The following description of the work performed by an AIIE Committee was submitted by the Committee Chairman, William K. Hodson of the H. B. Maynard Company—Editor.

In July of this year the Civil Service Commission published a set of position classifications for Industrial Engineers. These classifications now provide a comprehensive and definitive classification for Industrial Engineers.

While this classification only applies to Industrial Engineers in the federal service, it will become an important reference for defining the duties and activities of all Industrial Engineers.

Because of the effect that this classification will have on the Industrial Engineering profession in general, AIIE was very much interested in this project and took a very active part in providing counsel and guidance to the Civil Service Commission. Indeed, this project is typical of many that are constantly being undertaken by various members and committees of the Institute. A brief case history of this particular project will perhaps give many members some insight into some of the day-to-day activities of the Institute.

In October of 1958, the National Headquarters learned that the Civil Service Commission was undertaking a project to prepare position classifications for Industrial Engineers in the federal government. George Gustat, our National President at that time, realizing the importance of this project, immediately set up a group to work with the Civil Service Commission. This group was headed up by William K. Hodson, Executive Vice President of H. B. Maynard and Company. Known as "Task Force on Industrial Engineering Classification in Civil Service," this group worked under the energetic direction of the Professional Relations Committee whose Chairman at that time was Alex Rathe, now National President.

In November of 1958, Bill Hodson met with the people charged with the responsibility of preparing this classification. The Civil Service Commission had already completed some preliminary work on this project, but they were somewhat confused by the many varied activities that are associated with Industrial Engineering. Particularly confusing was the overlapping of activities of Industrial Engineers with activities of other classifications such as quality control engineer, work measurement analyst, organization specialist, operations research analyst, and the like. Consequently, while the Civil Service Commission was aware of the Institute's definition of Industrial Engineering, they were interested in obtaining a more specific list of Industrial Engineering activities and definitions of these activities. Since this one request represented a rather monumental task, Bill Hodson quickly recruited other members of the Institute to supplement his one-man Task Force. The completed Task Force consisted of the following individuals:

Mr. Robert K. Bogardus, Industrial Engineer
Transportation and Facilities Branch
United States Department of Agriculture
Washington 25, D.C.

Mr. Andrew N. Costas, Assistant Plant Industrial Engineer
United States Steel Corporation
Homestead, Pennsylvania

Mr. Robert B. Hewett, Chief Industrial Engineer
Crucible Steel Company
Pittsburgh, Pennsylvania

Mr. Paul D. O'Donnell, Assistant Manager
Power Circuit Breaker Department
Westinghouse Electric Corporation
East Pittsburgh, Pennsylvania

Professor Walter R. Turkes, Associate Dean
School of Engineering and Mines and Chairman,
Industrial Engineering Department
University of Pittsburgh
Pittsburgh, Pennsylvania

They first prepared a list of the major activities of Industrial Engineering with appropriate sublistings. They then parceled out this list of activities to each of the members of the Task Force who, in turn, prepared definitions and descriptions of each major activity and corresponding subactivities. During a series of conferences, various definitions and descriptions were reviewed, revised, and strengthened to reflect the viewpoints of all members of the Task Force. This preliminary "Definition and Description of Industrial Engineering Activities" was then reviewed by the full Professional Relations Committee and then by the entire Board of Trustees at the annual meeting of AIIE in May of 1959 in Atlanta, Georgia.

Since these groups represented many of the outstanding Industrial Engineers in the country, a number of very valuable suggestions and recommendations were received for improving the original draft. All of these recommendations were then incorporated into a final writeup which was again distributed to all members of the Board of Trustees and others who had a strong interest in this particular project. By July a final draft of the manual was prepared and presented to the Civil Service Commission.

After a careful study of this manual, the Civil Service Commis-

sion prepared a "Tentative Draft of Standards for the Industrial Engineering Series, GS-896-0, Classification Standards." They then submitted this tentative draft to AIIE and other interested groups both within and outside the federal government. While the Commission had done an outstanding job in the preparation of this tentative draft, the Institute felt quite strongly that the function of Industrial Engineering had been limited somewhat to industrial applications. As a result, the Task Force prepared a detailed critique of the tentative draft with specific suggestions for improving it. Again these suggestions were circulated among the Board of Trustees and other individuals interested in this project for additional comments and suggestions. These final comments were then passed on to the Civil Service Commission for their guidance in preparing the final draft of the Industrial Engineering Classification. These comments were submitted to the Commission in November, 1959.

In January of 1960, Bill Hodson again visited with the Commission in Washington to further explain the suggestions prepared by the Institute and to convince the Commission of the broad application of Industrial Engineering principles to all types of activities and not just those concerned with industrial type operations.

The final, and official version, of the Classification was published by the Civil Service Commission in July of this year (GS-896-D). This final Classification represents a great deal of thought and effort on the part of the Commission, and in general, is a very acceptable writeup from the Institute's point of view. Naturally there are some points of difference that still exist, but by and large this Classification is in agreement with the scope and definition of Industrial Engineering as established by the Institute.

This project merely represents one of the many projects constantly being worked on by various members of the Institute. By means of projects of this sort we are slowly, but constantly, creating a clear and professional image in the public eye of what Industrial Engineering is and what it is that Industrial Engineers do.

FEATURED SPEAKER

ROBERT PAXTON, President of General Electric has accepted the invitation as banquet speaker for the 12th Annual National Conference to be held in Detroit, May 11, 12 and 13, 1961.

12th Annual

AIIE NATIONAL CONFERENCE AND CONVENTION

May 11, 12, 13, 1961

Sheraton Cadillac Hotel

Detroit, Michigan

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CALENDAR

*February 1: "Organizing and Maintaining a Quality Control Function." Speaker: Jack Keyser, Bell Telephone Laboratories.

February 3-4: The Industrial Engineering Institute's program for Industrial Engineers and managers presented by the University of California at Berkeley and Los Angeles.

February 2-4: Material Handling Short Course, Georgia Institute of Technology, Atlanta, Georgia.

February 6-24: Oklahoma State University Executive Development Course sponsored by School of Industrial Engineering and Management. Write W. J. Bentley at O.S.U., Stillwater, Oklahoma.

*February 20: "Strategic Planning and Decision Making." Speaker: Dr. Herbert Jacobs, Dunlap and Associates.

February 27-March 3: "Materials Handling Analysis Conference." Write the University of Kansas Extension Center, 39th and Rainbow Blvd., Kansas City 12, Kansas.

*March 1: "How to Raise Productivity Through Better Supervision." Speaker: Dr. Raymond A. Katzell, Professor of Management Engineering and Psychology, NYU, College of Engineering and Director of Research Center of Industrial Behavior.

March 2-12: Third Inter-American Management Conference, Mexico City, Mexico. Write: Colonel Philip Garey, Vice President of Operations, Council for International Progress in Management, 247 Park Avenue, New York 17, N.Y.

March 13, 14, 15: "Labor Relations" Conference sponsored by the School of Industrial Engineering and Management, Oklahoma State University, Stillwater, Oklahoma.

March 17-18: Region IX Student Chapter Conference at the University of Houston, Houston, Texas.

*March 20: Forum on IE Problems as they affect Labor-Management Relations. Panel of Union, Management and Arbitrator Representatives. Moderator: Irving Gurfield, Attorney and Practicing Industrial Engineer, Barricini Candies.

March 20-31: Industrial Packaging Short Course, Purdue University Campus, Lafayette, Indiana. Write: Mark E. Ocker, Conference Coordinator, Division of Adult Education, Memorial Center, Purdue University, Lafayette, Indiana.

*April 5: "The IE Approach to Cost Reduction Through Cost Controls." Speaker: Dr. Alex W. Rathe, National President AIIE, Professor of Industrial Engineering, NYU, College of Engineering.

April 12-14: Purdue University's third Symposium on Information and Decision Processes, Purdue University, Purdue, Indiana.

*April 17: "Management Controls by Ratio Analysis." Speaker: Spencer A. Tucker, Partner, Martin and Tucker, Consultant Industrial Engineers.

April 20-22: Annual Convention of the Illinois Society of Professional Engineers in Peoria, Illinois.

June 5-16: Annual Work Design Intensive Course, Department of Industrial Engineering, Washington University, St. Louis, Missouri. Write to the Department for information.

*AIIE Metropolitan New York Chapter Workshop Subjects. All meetings held at National Cash Register Auditorium, 50 Rockefeller Plaza, New York City, at 7:00 P.M. Director of Workshops: Mitchell Fein.

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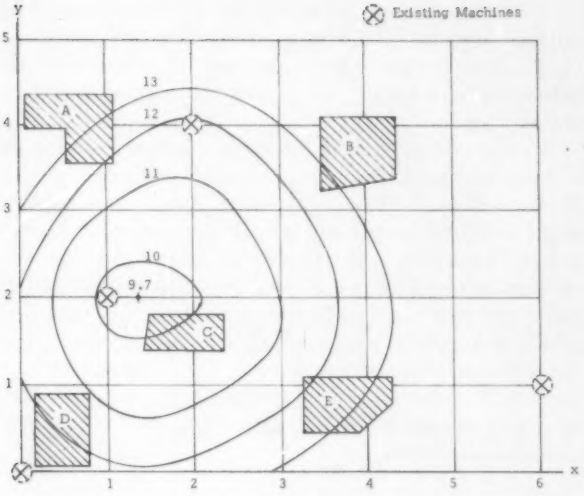

FIGURE 3

Eq. 4 with respect to both x and y and setting these equal to zero:

$$\frac{\partial M}{\partial x} = 0 \qquad \frac{\partial M}{\partial y} = 0 \qquad \text{Eq. 5.}$$

This is not an easy computation because of the square root involved in the expression and only furnishes a single M value. If the minimum point is not in an area available for location, the analytical approach is of little practical value.

RECTANGULAR MOVEMENT CASE

As previously pointed out, material flow along the straight-line path connecting two points of the layout can only be assumed if the material handling system to be used really allows full utilization of this shortest path. In other cases, a second method of measuring distances presented here may be more appropriate.

The distance between any two points of the layout is measured along directions parallel to a given pair of orthogonal axes. For example, the distance between the two points A and B in Figure 4 can be measured along one of many patterns, three of which are shown by (a), (b) and (c).

In every case, however, the length of the path is the same, namely:

$$|x_B - x_A| + |y_B - y_A| \qquad \text{Eq. 6.}$$

The basic assumptions of this model are as follows:

1. The material flow follows a rectangular pattern in directions parallel to two given orthogonal axes. Since a system of orthogonal aisles, usually parallel to building walls, covers the manufacturing area of many plants, this assumption is best suited for cases in which all handling of material is done in palletized unit loads by fork trucks. It also fits situations where tractors and trailers are used to handle packaged goods.

2. The material handling costs per unit of distance are the same between the new machine and each one of the existing machines receiving materials from, or supplying materials to the new machine, as in the straight movement case.

3. The material handling costs are directly proportional to the distance moved, again as in the case of the straight movement case.

RECTANGULAR MOVEMENT—SPECIAL CASES

In the simplest case, a single machine is present in the existing layout. If the system of coordinate axes is so located that this machine is at the origin and the axes parallel to the prescribed directions of movement, the measure of effectiveness M at any point (x, y) is:

$$M = |x| + |y| \qquad \text{Eq. 7.}$$

The level curves in this case, shown in Figure 5, are squares, centered at the location of the existing machine and tilted at an angle of 45°. The optimal location is at the origin. The further away from the origin, the less desirable the location. In this case, however, the same straight-line distance taken in different directions will result in different M values. The best direction, or direction along which the rectangular distance is minimal, is parallel to one of the coordinate axes; the worst direction is along a 45° line.

With two existing machines located at $(-d, 0)$ and $(d, 0)$ the measure of effectiveness M is:

$$M = \begin{cases} 2d + 2|y| & \text{if } |x| \leq d \\ 2(|x| + |y|) & \text{if } |x| > d \end{cases} \qquad \text{Eq. 8.}$$

M is independent of d in this case if $|x| > d$. The origin serves as center of gravity for the two existing machines. The level curves are shown in Figure 6. As in the straight movement case, the optimal location is on the segment connecting the two existing machines where $M = 2d$.

A similar pattern of level curves is obtained in cases where the two existing machines are located either on a horizontal ($y_1 = y_2$) or on a vertical line ($x_1 = x_2$). If these machines have the arbitrary locations (x_1, y_1) and (x_2, y_2) the calculation of the M value depends on the relative location of the point (x, y) with respect to the points

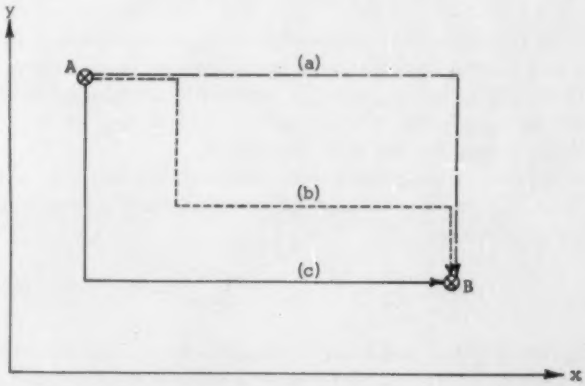

FIGURE 4

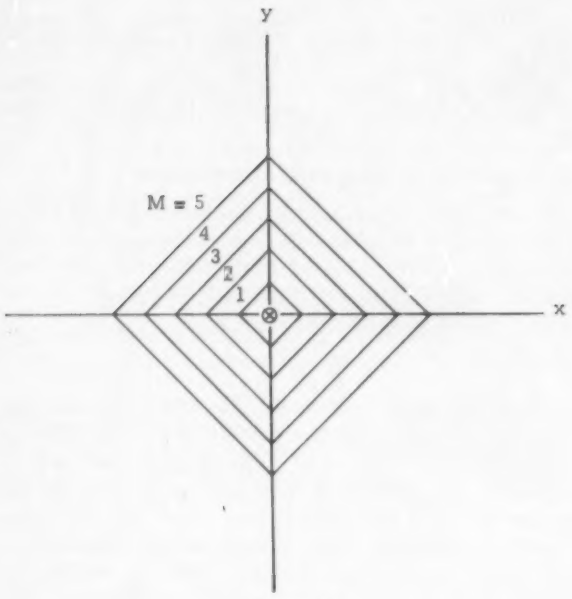

FIGURE 5

(x_1, y_1) and (x_2, y_2). Let $x_1 \leqq x_2$, $y_1 \leqq y_2$ and $C = (x_2 - x_1) + (y_2 - y_1)$, then:

TABLE 1

M Values for the Two Existing Machine Case Illustrated in Figure 7

Range in x	Range in y	M Values
$x_1 \leqq x \leqq x_2$	$y_1 \leqq y \leqq y_2$	C
$x < x_1$	$y_1 \leqq y \leqq y_2$	$C + 2(x_1 - x)$
$x > x_2$	$y_1 \leqq y \leqq y_2$	$C + 2(x - x_2)$
$x_1 \leqq x \leqq x_2$	$y < y_1$	$C + 2(y_1 - y)$
$x_1 \leqq x \leqq x_2$	$y > y_2$	$C + 2(y - y_2)$
$x < x_1$	$y < y_1$	$C + 2(x_1 - x) + 2(y_1 - y)$
$x < x_1$	$y > y_2$	$C + 2(x_1 - x) + 2(y - y_2)$
$x > x_2$	$y < y_1$	$C + 2(x - x_2) + 2(y_1 - y)$
$x > x_2$	$y > y_2$	$C + 2(x - x_2) + 2(y - y_2)$

Figure 7 shows the curves corresponding to this situation.

The optimal location includes any point (x, y) such that:

$$x_1 \leqq x \leqq x_2 \quad \text{and} \quad y_1 \leqq y \leqq y_2 \qquad \text{Eq. 9.}$$

This set of points represent an area of indifference in which further discrimination must be based on considerations other than distance. If the two existing machines are far apart, this model provides a great deal of flexibility in locating the new machine.

With n existing machines located at (x_1, y_1), (x_2, y_2), $\cdots$, (x_n, y_n) the measure of effectiveness M of a point (x, y) becomes:

$$M = \sum_{i=1}^{n} |x - x_i| + \sum_{i=1}^{n} |y - y_i| \qquad \text{Eq. 10.}$$

It can be shown that for an x equal to the median $\hat{x}$ of the values $x_1, x_2, \cdots, x_n$ the first term will reach a minimum, and similarly that for a y equal to the median $\hat{y}$ of $y_1, y_2, \cdots, y_n$ the second term will reach a minimum. The optimal location, where M is a minimum, is therefore at $(\hat{x}, \hat{y})$. Here we have, however, two different situations, depending on whether the number of existing machines is odd or even.

With an odd number of machines, the optimal location is the unique point $(\hat{x}, \hat{y})$. This situation is illustrated by a three-machine problem in Figure 8. The typical pattern of the level curves may be easily recognized. If all x_i's are ordered according to their algebraic values and if all y_i's are similarly ordered, each set of two consecutive x_i's and two consecutive y_i's delimits a rectangle, for example, ABC2 in Figure 8, within which all level curves have a common and fixed slope and are thus parallel to one another. In order to illustrate this point, the characteristic slope in each discrete rectangular area of Figure 8 is indicated as the fraction:

$$\frac{\Delta y}{\Delta x}$$

This peculiarity of the model can be utilized to construct level curves. In this graphical approach the following steps are necessary:

1. Delimit all discrete rectangular areas by tracing the lines $x = x_i$ and $y = y_i$ for $i = 1, 2, \cdots, n$.
2. Determine the medians $\hat{x}$ and $\hat{y}$. Every level curve is a closed line enclosing the median point $(\hat{x}, \hat{y})$.
3. Determine a few representative slopes. A simple way to develop the slopes is to start at one of the existing machines, for example at machine 3 in Figure 8, and graphically move around a level curve. The graphical reasoning might go as follows:

$$M \text{ at } 3 = |B1 + B3| + |C2 + C3| \text{ so that}$$
$$= |B1 + BC + C3| + |C2 + C3|.$$

Then

$$M \text{ at } D = |B1 + BC + CD| + |CD + C3| + |D2|,$$

but

$$|CD + C3 + D2| = |C2 + C3|,$$

therefore

$$M \text{ at } D = |B1 + BC + CD + C2 + C3|.$$

Because

$$M \text{ at } 3 = M \text{ at } D,$$

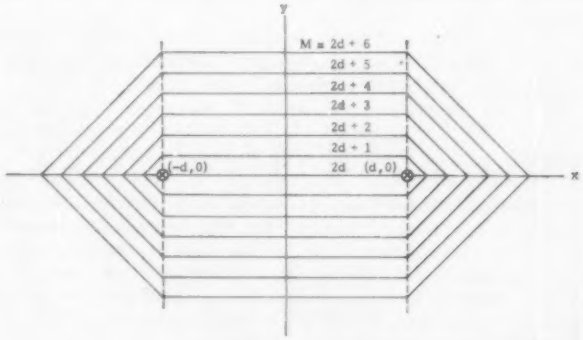

FIGURE 6

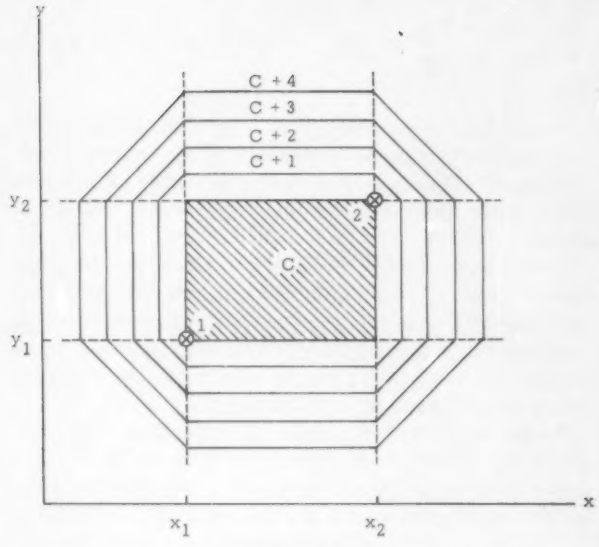

FIGURE 7

it follows that

$$|B1 + BC + C3 + C2 + C3| = |B1 + BC + CD + C2 + C3|$$

or

$$|C3| = |CD|.$$

Graphically this indicates that point D is down $C2$ a distance CD, or that triangle $CD3$ is a 45° right triangle. The slope of this segment of the level curve is the slope of $D3$, that is $\Delta y/\Delta x$ is $+1/1$. All level curve segments contained within this delimiting rectangle, i.e., $C3E2$, will have this same slope of $+1/1$.

4. These values can then be extended to other areas by symmetry after appropriate changes are made. In particular, the "diagonal areas" (indicated in Figure 8 by * and **) form a 45° angle with the coordinate axes.

5. Once the set of slopes has been determined, each level curve is constructed, segment by segment, starting from any arbitrary point. A check on accuracy is provided by the fact that each curve is a closed line.

With an even number of existing machines, the median point $(\hat{x}, \hat{y})$ is not a unique optimal location. In this case, as already found in the two-machine case with arbitrary locations, the optimum includes many points, all of which are within the central rectangular area enclosing the median point $(\hat{x}, \hat{y})$. This situation is illustrated by a four-machine problem in Figure 9.

The level curves shown in this figure have again a regular pattern of areas with characteristic slopes. They can be constructed with the same steps as in the case of an odd number of existing machines. The fractions indicate slopes and the asterisks (*,**) diagonal areas as in Figure 8. It can be noted that in all cases as one gets further and further away from the set of existing machines the level curves tend to approach more and more the square shape of Figure 5 except for minor irregularities at the corners. As far as those extreme locations are concerned, the problem can be simplified by replacing the n existing machines by a single machine located at the center of gravity $(\bar{x}, \bar{y})$ where:

$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad \bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i \qquad \text{Eq. 11.}$$

In situations where the existing machines are clustered in groups the replacement of several machines by a single one located at the center of gravity $(\bar{x}, \bar{y})$ can be used to reduce the size of the problem without appreciable loss in accuracy. In such cases, however, it will often be necessary to introduce the weighting scheme described below in order to maintain the relative importance in the number of existing machines.

STRAIGHT VERSUS RECTANGULAR MOVEMENT

The consequences of assuming a straight movement rather than a rectangular movement in a layout problem, or vice versa, can best be illustrated by listing the major differences between the two models:

1. The straight-movement path between any two points of a layout is always shorter, or in special cases equal to, the corresponding rectangular-movement path. Consequently:

2. In any given problem, the rectangular level curve will always be enclosed in the corresponding straight-movement level curve with the same M value.

3. In any given problem, if a segment of a rectangular level curve approximately overlaps a segment of a straight-movement level curve, it will have a higher M value.

4. The rate of increase in the measure of effectiveness, as indicated by the density of level curves, is higher with the rectangular movement than with the straight movement.

5. In any given problem, the angularity of the rectangular level curves and the existence of indifference areas often create local differences in the measure of effectiveness M between the two models. These differences seldom result in a reversal of the order of preference of discrete candidate areas when changing from one model to another although examples can be constructed in which this occurs. If a reversal occurs, the candidate areas involved are close competitors.

6. The rectangular movement provides a higher degree of flexibility for the location of new equipment than the straight

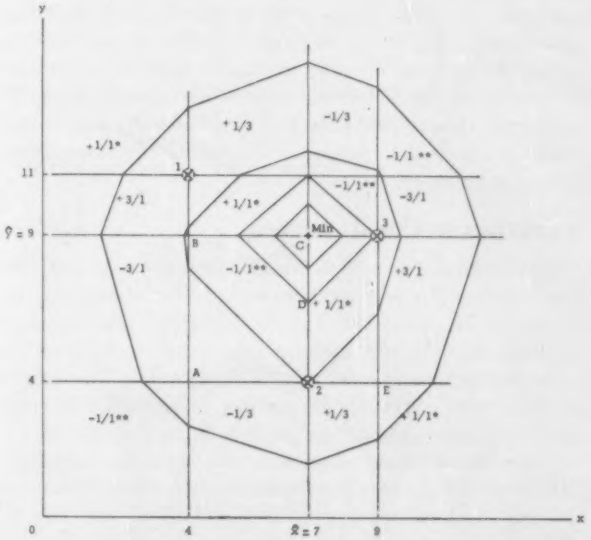

FIGURE 8

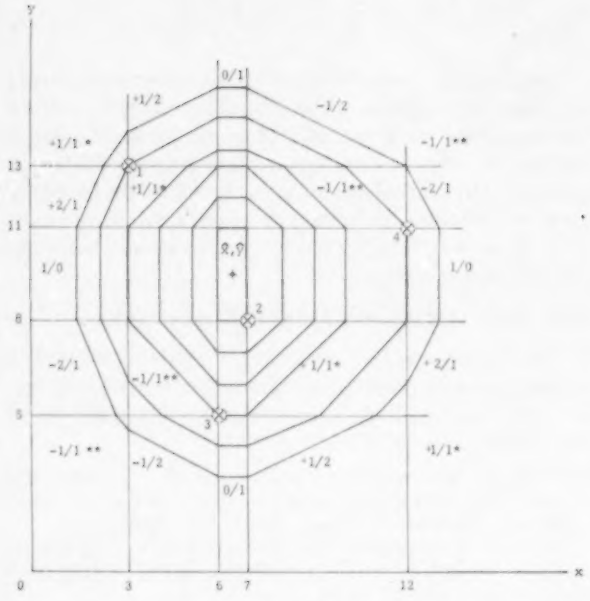

FIGURE 9

movement because it often has large areas of indifference around the optimal location. This flexibility is particularly advantageous for the consideration of other location factors ignored in the measure of effectiveness selected.

All these differences are illustrated in Figure 10, where the four-machine problem previously shown in Figure 3 is reproduced with both sets of level curves.

As far as the practical applications are concerned, the differences between the two models are relatively unimportant. The optimal location of new equipment is not very sensitive to the path pattern selected. Thus, even if a straight-line path would be a more appropriate assumption to make in a given problem, a rectangular movement may be substituted without major shift in either the optimal location or in the relative preference of various available candidate locations. Simplicity in determining the optimal area and in graphically constructing level curves is a definite advantage of the rectangular movement model.

WEIGHTED MATERIAL FLOW

Assumption 2 of either model requires equal material flow between the new machine and each existing machine involved. In many situations, however, the volumes handled are definitely unequal, the costs are different or some flow paths are more critical than others. The simple methods previously introduced can be extended to such situations by appropriately weighting the flow paths.

Let w_i be the relative weight given to the material flow path between the new machine located at (x, y) and the existing machine located at (x_i, y_i), then the measure of effectiveness M at (x, y) in the straight movement case will be:

$$M = \sum_{i=1}^{n} w_i \left| \sqrt{(x - x_i)^2 + (y - y_i)^2} \right| \quad \text{Eq. 12.}$$

In general the introduction of weighting factors will result in distorting the level curves of the unweighted case. Compare, for example, Figure 2 with Figure 11, in which the relative weights $w_1 = 1$ and $w_2 = 2$ have been introduced.

In order to preserve the simplicity of the graphical approach in the rectangular movement case, let each existing machine i with relative weight w_i be replaced by w_i machines all located at (x_i, y_i). The weight w_i must be an integer but since all w_i can be arbitrarily selected, this requirement is not a serious limitation.

An example will illustrate the practical approach. There are three existing machines, A, B and C, located respectively at (5, 9), (2, 4) and (11, 6). Their relative weights are $w_A = 2$, $w_B = 1$, and $w_C = 3$. Let A be replaced by 2, B by 1, and C by 3 artificial machines all with weight 1. The resulting optimal location and a representative level curve are shown in Figure 12. In this figure one can note that the available candidate area R which is located within the triangle ABC is less desirable than area S located outside of ABC. Intuition is a dangerous guide in problems with weighted flow.

This generalized graphical approach retains the original simplicity of the rectangular movement. The weighting factor can be used to introduce differences in product characteristics (size, shape, weight, etc.) or in plant and job conditions (traffic frequency, handling methods, local conditions, etc.). Although linear weighting schemes cannot accommodate all possible situations, they do allow the application of the proposed models to a great number of problems and provide, therefore, a valuable extension of the original unweighted situation.

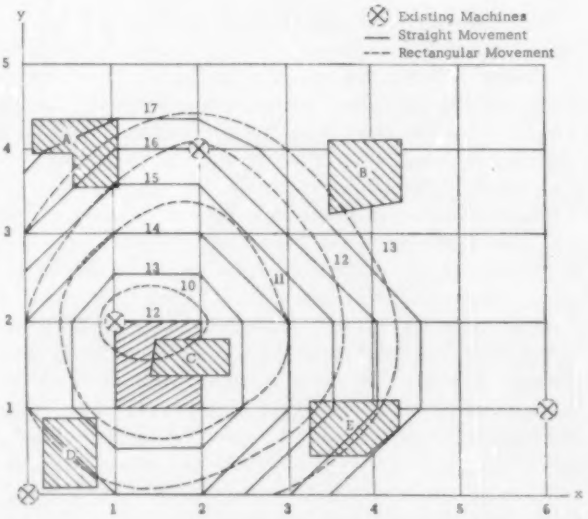

FIGURE 10

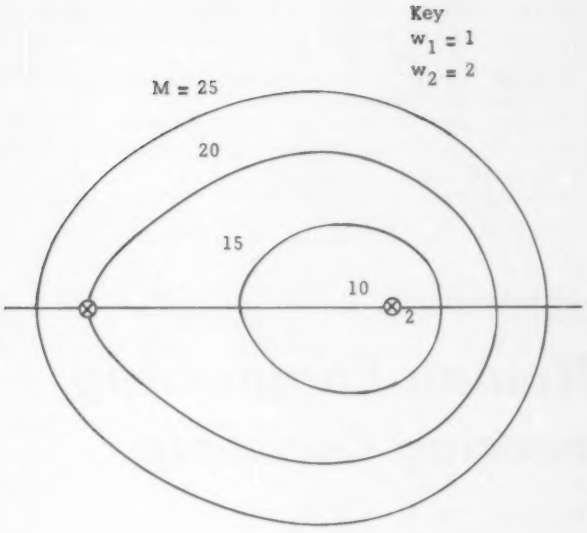

FIGURE 11

ADDITION OF MANY MACHINES—RELAYOUT—NEW LAYOUT

All discussions so far were limited to the addition of a single new machine to an existing fixed layout. If two or more new machines must be added, the problem is radically changed. Each machine must be so located that the system of all new machines is optimal rather than the location of each individual machine. If some of the existing machines may be relocated, they are to be considered as new machines.

If the set of existing machines exchanges the same amounts of material with each of the new machines, then there will exist a unique set of level curves applicable to locating all new machines. The remaining difficulty in this case will consist of taking full advantage of the local conditions existing in the neighborhood of the optimal location, since this will be common for all new machines. The existence of indifference areas simplifies somewhat the difficulty of clustering many new machines around the optimal location.

If the sets of existing machines are different or if the material flow is weighted, there will be a characteristic set of level curves for each new machine. If all new machines may be optimally located, each individually, without mutual interference, the repeated application of the previous approach to each new machine leads to an overall optimal solution.

If interferences exist, the problem becomes extremely complex. A simple approach consists in defining discrete candidate areas and in formulating the problem in a combinatorial framework. An algorithm for finding the optimal combination or progressing from one combination to a better one is conceivable but not yet available. Examining all combinations becomes rapidly impractical with increasing numbers of new machines.[1] The two proposed models can only be generalized to multiple new machine additions in special cases. In other cases, in relayout problems or in new layouts, the traditional trial and error method still remains the only practical approach. The proposed models only contribute to the extent that they conceptually increase the understanding of the underlying principles.

A considerable amount of work has been done recently with job shop simulation for analysis of problems involving scheduling and planning. However most of these simulators describe only the time dimension. With rapidly increasing capacities of computers it appears quite feasible to extend some of these simulators to include spacial relationships, such as dimensions of machines, storage areas and aisles. This type of simulation would enable the layout analyst to examine economically numerous alternative arrangements.

CONCLUSIONS

The models presented here furnish a practical method for determining the optimal location of a new machine in existing and fixed layouts in cases where the flow distance is the major location factor. This method can be extended to more general situations by introducing appropriate changes but loses a great part of its practical value if many new machines are to be added to the existing layout. Other problems, such as the orientation of the new machine in its optimal location or the introduction of the

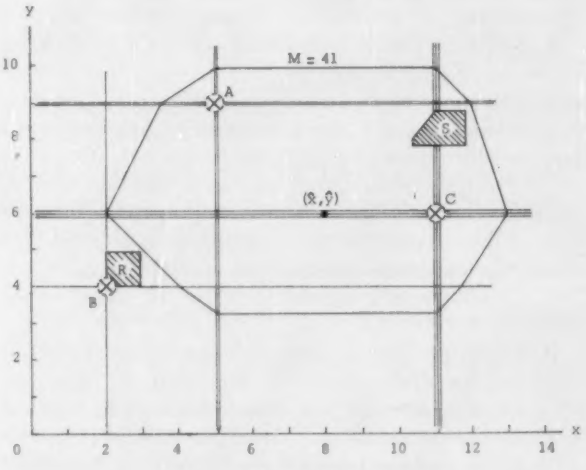

FIGURE 12

[1] One of the reviewers of this article observes that if one is willing to compute a measure of effectiveness for each new machine at each location, an overall optimum can be achieved according to the assignment problem, which can be solved with linear programming. Although the assignment problem is extremely prone to degeneracy, special solution procedures are available which suggest that this approach appears promising.

third dimension in the layout arrangement, have been left unsolved. It is hoped that methods will be developed in the future for the solution of these problems and a wider applicability of the results obtained.

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The Relationship of Human Engineering to Industrial Engineering Concepts

by **H. JERRY LAVENDER, JR.**

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IN AN ISSUE of *The Journal of Industrial Engineering* (9), a "Recent Readable" review of the article "Human Engineering" used 20 lines to describe the article, and included these two sentences: "Human engineering is a young and unfamiliar field. More will undoubtedly be heard about it in the future." It cannot be said that this is the future, but the present writer will point out that certain functions of this "young and unfamiliar field" are as old as various phases of Industrial Engineering.

Just what is human engineering? How old is it? What functions are performed? It may be said that human engineering, or human factors engineering, is the application of the facts, skills, and techniques of the biological and social sciences to equipment design (8). To put it another way, it is the mating of man to machine wherein optimum compatibility is achieved; it is, therefore, adjusting the machine *to* man (a revolutionary idea) to obtain the best multi-man-machine relationship.

ORIGIN

Basically, the idea is not a new one to the Industrial Engineer. He is fully aware that the efforts of Taylor and the Gilbreths were the first major attempts to improve man-machine relationships. These efforts were primarily attempts to increase machine productivity by improving the work habits of the operator; that is, man was the variable which had to adjust to the machine (7). Human engineering has reversed this procedure; the machine has become the variable. This reversal was spawned by World War II when equipment (or "weapon systems") became more complicated and difficult to operate. The question therefore arose: "Why not design equipment (weapon systems) to secure optimum operation in terms of human capabilities, limitations, and variability (7)?"

It was probably noticed that the term "weapon system" appeared parenthetically in the above paragraph. One may prefer to use this term in lieu of "equipment," since a definition of a weapon system *must* include the human, i.e., a weapon system is an instrument of combat, together with all related equipment, humans and skills, necessary to support and operate the instrument of combat as a single unit of striking power (8). Man has thus been given the nomenclature of "Personnel Subsystem."

At first, engineers (very few of them industrial) attempted to allow for the human factor, but it soon appeared that other disciplines were required. Since the human was the element involved, the experimental and industrial psychologists were brought into the picture; and thus originated the field of engineering psychology. Soon, physiologists, physicians, anthropologists and related callings formed a team approach in the solution of problems affecting human interaction (7); thus the field of human factors engineering was *reborn*.

The term "reborn" is used to indicate that a team of engineers and psychologists is not new. Frank B. Gilbreth was an engineer, and his wife was trained in psychology (1). It is well known that the two of them worked together very closely; their training complemented each other. They served as a check on each other so that the human element did not cause neglect of the mechanical, and vice versa (1).

THE STARTING POINT

It is immediately apparent that the place to introduce human engineering is at the beginning of a program rather than after completion of the technical design. This is true for equipment *per se*, the layout of the area (room,

trailer, plane, ship compartment, etc.), and the development of necessary training programs, following a complete task analysis.

How can this "complementary" approach be utilized today by a team? Figure 1 depicts the approach followed by the writer's group at the Electronics and Ordnance Division of Avco. It is not extraordinary, as most human engineering groups follow similar procedures. The Industrial Engineer, in many cases, does likewise, since the scope of methods engineering includes defining the problem related to expected costs, breaking the job down into operations, analyzing each operation to determine the most economical procedure (and) applying proper time values (6).

DIFFERENCES AND SIMILARITIES

The human engineer's approach is not as directly related to costs as is the Industrial Engineer's, although it does play a role, and here we do have a difference in *modus operandi;* otherwise, a procedure generally utilized by the human engineer, as depicted in Figure 1, is also applicable to the Industrial Engineer. It may be stated verbally, as follows:

1. Become thoroughly acquainted with the system.
2. Make a preliminary list of human tasks and requirements utilized by the system. This includes the tentative assignment of functions to one or more men, i.e., assignment which will result in economy of operation, optimal communication, work flow, and size of team.
3. Decide which of the tasks, if any, had best be performed by machine (see Table 1).
4. Decide and list the step-by-step procedures to be followed by man (personnel subsystem). The relationship of each operator to every other operator and to the equipment may be shown in an organizational and/or flow diagram. Furthermore, all functions should be checked against a time-line analysis to insure against overloading; design and manning must be directed where the demands are the greatest.
5. Decide whether the equipment design is compatible with man's requirements, capabilities, and limitations; if not, redesign may be required, within cost allowances. (Is this too different from designing a better holding device, for example, so that a production operator may better utilize both hands?)

TABLE 1

Areas in Which Man or Machine are Functionally Superior with Respect to Each Other (3)

Man excels at:

1. Sensing or detecting minimum amounts of visual or acoustic energy (in his sensory spectrum).
2. Perceiving patterns of light and sound (in his sensory spectrum).
3. Improvising and using flexible procedures.
4. Storing large amounts of information over long periods and recalling relevant facts at appropriate times.
5. Reasoning inductively.
6. Exercising judgment.

Machines excel at:

1. Responding rapidly to control signals.
2. Applying great force smoothly and precisely.
3. Performing repetitious, routine tasks reliably.
4. Storing information and erasing completely.
5. Reasoning deductively, including ability for computation.
6. Handling highly complex operations—many tasks at once.

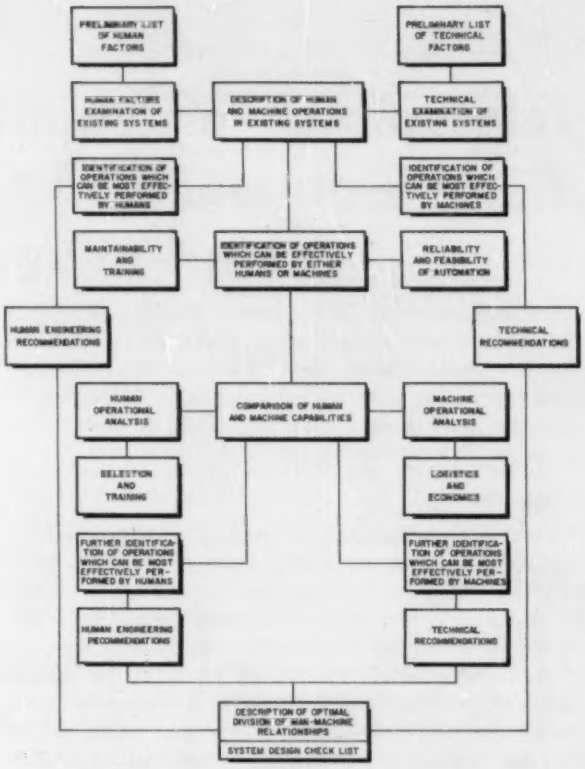
PRELIMINARY LIST OF HUMAN FACTORS
PRELIMINARY LIST OF TECHNICAL FACTORS
HUMAN FACTORS EXAMINATION OF EXISTING SYSTEMS
DESCRIPTION OF HUMAN AND MACHINE OPERATIONS IN EXISTING SYSTEMS
TECHNICAL EXAMINATION OF EXISTING SYSTEMS
IDENTIFICATION OF OPERATIONS WHICH CAN BE MOST EFFECTIVELY PERFORMED BY HUMANS
IDENTIFICATION OF OPERATIONS WHICH CAN BE MOST EFFECTIVELY PERFORMED BY MACHINES
MAINTAINABILITY AND TRAINING
IDENTIFICATION OF OPERATIONS WHICH CAN BE EFFECTIVELY PERFORMED BY EITHER HUMANS OR MACHINES
RELIABILITY AND FEASIBILITY OF AUTOMATION
HUMAN ENGINEERING RECOMMENDATIONS
TECHNICAL RECOMMENDATIONS
HUMAN OPERATIONAL ANALYSIS
COMPARISON OF HUMAN AND MACHINE CAPABILITIES
MACHINE OPERATIONAL ANALYSIS
SELECTION AND TRAINING
LOGISTICS AND ECONOMICS
FURTHER IDENTIFICATION OF OPERATIONS WHICH CAN BE MOST EFFECTIVELY PERFORMED BY HUMANS
FURTHER IDENTIFICATION OF OPERATIONS WHICH CAN BE MOST EFFECTIVELY PERFORMED BY MACHINES
HUMAN ENGINEERING RECOMMENDATIONS
TECHNICAL RECOMMENDATIONS
DESCRIPTION OF OPTIMAL DIVISION OF MAN-MACHINE RELATIONSHIPS
SYSTEM DESIGN CHECK LIST

FIGURE 1. A Human Engineering Work Approach to Man-Machine Systems.

6. Develop a training program, based upon personnel requirements derived from a task and time analysis.
7. Plan the layout of the various equipments to achieve optimum work and communication flow. This includes the delineation of usable work area, i.e., on the basis of accessibility and sensory capabilities; and further delineation of the specific work area based upon primary, simultaneous and sequential functions.

Such a procedure will cause various questions to arise, the answers to which will further develop an optimum man-machine relationship. For example:

1. Does the equipment design give the operator the information he requires in order to perform his various tasks?
2. Are incompatible activities required simultaneously of the operator (4)?
3. Are space, weight, and bodily dimensions and human capabilities compatible?
4. In general, is the man being utilized so as to contribute most effectively to the achievement of the system's mission (4) or the production of an item?
5. Are redesign, training requirements, training equipment, and related human-oriented factors compatible with cost and schedule requirements?

It may therefore be said that, in the final design (and/or operation) of any system or system element, all factors must be evaluated with respect to both technical feasibility and economic considerations (3). The data given in Table 1, if followed, allow for both of these con-

TABLE 2

Specialty Distribution of Personnel Performing Human Engineering

Specialty	Number	Percentage
Psychologists	133	37.8
Engineers (all types)	101	28.7
Others (physicians, physiologists, technicians, administrative)	118	33.5
	352	100.0

siderations; to require either man or machine to infringe upon each other's capabilities is neither technically correct nor economically sound. The Industrial Engineer would do well to keep the information in Table 1 at his fingertips at all times, for the data are as valuable to him as to the Human Factors and Design Engineers.

SUMMARY

With such obvious areas of similarity between human engineering and Industrial Engineering, and with a "common beginning," it is surprising that there are so few Industrial Engineers in the human engineering field. The author knows of only one survey in which an attempt was made to ascertain qualifications of those performing human engineering work. That survey was made by Kraft (5) of Lockheed Corporation, Marietta Division, in late 1957 and reported to responding companies in April, 1958. Forty-nine companies, with a total of 352 employees performing human engineering or closely related work, answered the survey questionnaire. Of this number, only one Industrial Engineer was reported, representing less than .3% of the total; yet, other engineering disciplines (mechanical, electrical, aeronautical, and "other") totaled 101 or 28.7%. Table 2 shows the author's analysis of Kraft's findings.

True, nothing has been mentioned regarding the research and experimental work performed by human engineers; and this probably accounts for the number of psychologists in the field (besides the reasons stated earlier in this article). Human engineering requires knowledge of human behavior as well as sensory, intellectual, and physiological capabilities and limitations. Nevertheless, one writer (2) points out a dichotomy in which he believes human problems must be considered, i.e., *research* in human engineering and *practice* of it; and he proposes that the practitioner be an engineer.

The present writer is not taking sides; this article is not meant to be an editorial. The foregoing paragraph and the general purpose of this article, as a whole, are to merely point out that the engineer, and specifically the Industrial Engineer, may find it challenging to be a part of the research and development of man-machine systems as against the operational aspects of industry.

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CHANGES

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INDUSTRIAL ENGINEER

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The Metamorphosis of Industrial Engineering into Management Engineering—Plea for Change in Name*

by JOSEPH D. CARRABINO

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ON MAY 12, 1960, the writer presented a paper (1) on "Some Proposals for a Unified Program of Management Controls" to the Eleventh Annual National Conference of the American Institute of Industrial Engineers in Dallas, Texas. In this paper he examined the metamorphosis which Industrial Engineering has undergone, and strongly urged that the AIIE give immediate consideration to changing its name to one which is in greater consonance with the emerging broad field of applied management sciences. During and since the Conference, he has been deluged with verbal and written communications supporting the views expressed, and urging that a serious campaign be launched to get full consideration of this matter from the officers and members of AIIE. In view of this overwhelming reaction, the writer felt an obligation to sound the clarion and to thrust the challenge before the AIIE. This is the purpose of this article.

Before embarking on a discussion of the Industrial Engineering profession, it may be profitable to take a kaleidoscopic view of what the writer likes to call the three industrial revolutions which have set the stage for the current environment in which the profession finds itself.

FIRST INDUSTRIAL REVOLUTION (MECHANIZATION)

Here we began to substitute machinery for the human and animal "brawn" contributions to a production system. Approximate dates quoted by historians for this First Industrial Revolution are: England about 1770, and the United States about 1790. The principle of specialization of labor was widely adopted as we replaced more and more hand work by machinery. The invention of machine tools (the "master tools" of industry) made possible interchangeable manufacture. The developments were all essential concomitants of mass production techniques.

SECOND INDUSTRIAL REVOLUTION (SCIENTIFIC MANAGEMENT MOVEMENT)

This Second Revolution got under way in the United States about 1900 under the leadership of Frederick W. Taylor, who is considered the "father" of the scientific management movement. His contributions reflected the philosophy of substituting a fact-finding approach for rule-of-thumb operation. Essentially, we can say that he demonstrated the efficacy of applying scientific methodology to the analysis of "man and machine" systems whereas prior to this time such methodology was applied only to physical systems. Since the end of World War II we have seen the development of many new and more sophisticated methodologies and techniques such as operations research, linear programming, game theory, job enlargement, and electronic data processing using high-speed digital computers.

The scientific management movement has given impetus to the:

1. development of emphasis on study of human relations problems,
2. growth of management development programs of all types at all managerial levels,
3. growth of the labor movement and its many programs for coping with problems generated by the industrial revolutions,
4. growth of a professional "managerial class."

THIRD INDUSTRIAL REVOLUTION (AUTOMATION)

During and since the end of World War II we have begun to substitute for the "brains and sensory apparatus" of human beings in production systems. Automated equipment is characterized by servomechanisms which include sensing devices to tell when a process is out of control and signal control devices to make proper adjustments.

The common demoninator between all three industrial revolutions is that the human contributions to the production system are eliminated, reduced, or modified. Recent developments of numerically-controlled machine tools are especially worthy of note to the Industrial Engineer, since they portend radical changes in industry

* *Editor's Note:* Reader reactions and comments to this article are encouraged in article form or a form suitable for publication in the Reader Comment section of the *Journal.*

which will diminish further the human component in production systems. The Industrial Engineer's tool kit for rationalizing and measuring manual effort will become less and less useful as this effort is replaced by mechanization and automated equipment. Increasingly useful will become the knowledge of computer technology and the techniques for conducting equipment replacement studies.

STATEMENT OF THE MANAGERIAL FUNCTIONS

It may be well at this time to state the functions of managers and to see where Industrial Engineering has made contributions and, even more important, where this profession might realize its fullest potential. The functions of all managers at all levels in all enterprises may be defined as follows (5):

1. *Planning* involves the selection, from among alternatives, of enterprise objectives, policies, procedures, and programs.
2. *Organizing* involves the determination and enumeration of the activities required to achieve enterprise purposes, and the grouping of these activities, the assignment of them to a subordinate manager and the delegation of authority to carry them out, and provisions, to permit the desired type of coordination among managers and subordinates.
3. *Staffing* comprises those activities which are essential in manning, and in keeping manned, the executive positions in an enterprise.
4. *Direction* embraces those activities which are related to guiding and supervising subordinates.
5. *Control* includes those activities which are designed to compel events to conform to plans. This formulation of the concept embraces the idea that the planning activities must precede control and that plans alone are not self-achieving. The control process involves three steps:
   a. The determination of standards—"what should be accomplished."
   b. The appraisal of performance—"what has been accomplished."
   c. Comparison of the actual performance with standards and correction of deviations.

A statistical quality control chart is an example of a control device whose use embodies the three steps of the control process.

CONTRIBUTIONS OF INDUSTRIAL ENGINEERING

The Industrial Engineering profession has contributed chiefly to the performance of the managerial function of control. Beginning with the works of Frederick W. Taylor, the Industrial Engineering profession has been intimately associated with manufacturing activities. The techniques of methods improvement, work measurement, wage incentives, and plant layout have been most prominent. Unfortunately, this is still the predominant situation in American industry. This is the connotation which the words "industrial engineering" still have not only among laymen but also among businessmen and academicians.

Historically and currently cost reduction and cost control programs in industry have been focused on the manufacturing function. Industrial Engineers with some help from accountants have been called on to provide the know-how to perform the three steps of the control process in manufacturing. This partial and suboptimization approach to cost control is still the vogue today as seen in recent announcements of cost reduction training programs conducted by such elite organizations as the American Management Association.

Industrial Engineering has been called on to help in performing the managerial function of planning to a very limited extent. Perhaps it may be argued by way of excuse that this is the most neglected of all managerial functions and that the fault lies with management. On the other hand, it may be argued that management usually adopts methods when they are available and their efficacy has been demonstrated.

An examination of the situation with regard to the planning and control of operations in the other functional areas of management such as research, engineering, and marketing reveals a distressing picture. Management has only in rare instances called on Industrial Engineers to exercise their skills in these areas. Tremendous opportunities for cost reduction and control exist in these areas, particularly in government financed industries such as aircraft and missiles where, for example, under-utilization of engineers is mistaken for a shortage of engineers. The problem of measurement is indeed difficult in these non-manufacturing areas but Industrial Engineering techniques such as work sampling could be adapted to replace the present informal controls with measurement-based controls.

Industrial Engineering applications in non-manufacturing fields have been numerous in post-war years but we must not overlook the fact that the techniques used have been fairly elementary; i.e., work simplification.

Now we shall examine the contributions of other groups who purport to contribute to the performance of the managerial functions of planning and control. These groups comprise the ancient controllers' fraternity and the latter-day brotherhood of operations researchers.

FUNCTIONS OF THE CONTROLLER

The functions of the controller, as determined from a study of a number of company organization manuals, job descriptions, and interviews, are summarized (American Management Association Research Report No. 20) by Dale (2) as follows:

1. Providing basic information for managerial control through formulation of accounting and costing policies, standards and procedures, preparation of financial statements, and maintenance of books of account; direction of internal auditing and cost controls.
2. Budgeting and control of operations and results.
3. Specific control activities.
   (a) General accounts, primary and subsidiary accounts; devising checks on the company's finances and safeguarding its assets; checking invoices, accounts receivable and payable; controlling cash payments and receipts, payroll accounts, fringe benefits, plant and equipment records; cost accounting activities of the various management functions.

(b) Preparation and interpretation of regular financial reports and statements.
(c) Inventory control.
(d) Statistics.
(e) Taxes.
4. Internal audits.
5. Interpretation of control data.

Historically, the controller has been the chief accounting officer of a company. He has concerned himself primarily with statistical and financial data and the emphasis has been on the reporting of historical information. When looked at from the modern concept of control, the name controller appears to be a misnomer since in fact only part of the control process has been performed. There is very little in the educational background of accountants which would prepare them to perform measurement activities, and in the writer's opinion measurement is the essence of the control process. If this is so, then it is obvious that any educational process which includes scientific methodologies would provide excellent preparation for the performance of the control process.

From the viewpoint of the managerial function of planning, it is difficult to see how the controller's function as currently practiced could make significant contributions. The simple methodologies and equally simple techniques comprising the tool kit of the controller could hardly cope with the complexities presented by analyses requisite to the "selection from among alternatives of objectives, policies, procedures and programs."

FUNCTIONS OF OPERATIONS RESEARCH

In April, 1951, the Committee on Operations Research of the National Research Council published a brochure entitled "Operations Research with Special Reference to Non-Military Applications" with the object of acquainting American management with what was then a new management tool. At that time, operations research, as an organized activity under that name, was already more than ten years old and had amassed a distinguished record of accomplishment for the military, both British and American, in World War II—and was adding to its record of military accomplishment in Korea. This and subsequent events have had a "sputnik like" effect on the Industrial Engineering profession.

Ellis Johnson claims (7) that the most important characteristics of operations research are:

1. Research on the operations of the whole organization.
2. Optimization of operations in a manner that brings about greater assurance of both short and long range health for the organization.
3. Application of the newest scientific methods and techniques.
4. Synthesis and extension of the methods and techniques of the older management sciences.
5. Development and use of analytical models in the manner common to the basic sciences.
6. Design and use of experimental operations that give an insight into the behavior of actual operations.
7. Use of integrated and creative multi-disciplinary team research to solve complex operational problems.

The Institute of Management Sciences is another organized group whose objectives, "to identify, extend, and unify scientific knowledge that contributes to the understanding and practice of management," appear to parallel those of the Operations Research Society of America and those of the AIIE as stated in the official definition of Industrial Engineering which was adopted in 1955:

> Industrial Engineering is concerned with the design, improvement, and installation of integrated systems of men, materials and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design, to specify, predict, and evaluate the results to be obtained from such systems.

The dividing line which the writer believes will gradually form between these three groups is that ORSA and TIMS will concentrate on more basic and mathematically oriented management sciences, whereas AIIE efforts (at the best level) will concentrate on applied management sciences. This dividing line is analogous to that between physics and chemistry with engineering. This appears to be a proper division of labor between these groups.

UNIFIED PROGRAM OF MANAGEMENT CONTROLS

It should be obvious by now that a unification of the measurement-oriented elements of the controller's function, Industrial Engineering, and operations research is desirable since all three groups purport to have similar philosophies and objectives. The writer believes that we can accelerate this unification by combining the measurement-oriented elements of these three fields into a new field which he should like to call *management engineering*. In other words:

Controllership Function + Industrial Engineering + Operations Research = *Management Engineering*.

The writer proposes setting up a separate management engineering group for each functional area of management: i.e., research, engineering, manufacturing, and marketing. He proposes a separate management engineering group at the general management level. This central unit would be responsible for coordinating and integrating the efforts of each of the functional area units.

The management systems in each of the functional areas and at the general management levels have characteristics sufficiently different to warrant the use of specialized management engineering groups. The need at the general management level is particularly critical because of the rapid development of new technologies which are making possible the rapid processing of large amounts of information and the simulation of management decision-making processes by means of high-speed computers. More and more articles, (3) and (6), in the recent literature discuss this critical need.

If it would assuage the feelings of the more sentimental members of AIIE, the writer would have no objection to retaining the name Industrial Engineering to describe the

applications of management sciences to the manufacturing function.

PROPOSED CHANGE IN NAME IN AMERICAN INSTITUTE OF INDUSTRIAL ENGINEERS

The writer strongly urges that the AIIE give immediate consideration to changing its name to one which is in greater consonance with the emerging broad field of applied management sciences. Since the word management sciences is becoming widely associated with work related to the development of fundamental analytical tools and methodologies it would seem logical to use the name management engineering to describe the work related to the application of these fundamental tools and methodologies to management systems. The present image of Industrial Engineering held by people outside the profession (also by many within) is not consonant with the image created by the official definition adopted by the AIIE. The very best current practice and certainly the majority practice of the future merit a break with many past practices which could hardly be classified as professional activities. In fact, if present trends are allowed to continue, people called Industrial Engineers will be thought of and used as technician-like assistants to the "professional" operations researchers and management scientists.

The present (mostly simple) and future (we hope sophisticated) applications of Industrial Engineering to non-manufacturing areas warrant a break with the restrictive word "industrial" with all its manufacturing connotations. The ever-present image of the time study man as a technician bears approximately the same relationship to an Industrial Engineer as a nurse does to a physician. At this point the writer would like to quote an outstanding member of AIIE, whose letter illustrates some of the practical difficulties now being experienced because of the widely existent narrow interpretation of Industrial Engineering:

> Today I read a copy of the proceedings of the 11th National AIIE Conference containing your talk on Management Controls. Your proposal on changing the name of the American Institute of Industrial Engineers and the recommendation of the term Management Engineering is a much needed change. I hope you will carry on your crusade and write the additional paper you mentioned in your talk listing some of the reasons. I would like to give you some problems we have had because of the term "Industrial Engineering." During the past year I have been a member of the Task Force of the AIIE to assist the U.S. Civil Service Commission in properly describing Industrial Engineering jobs in the government service. The government people write very narrow job descriptions and base all of their write-ups too much on the word "Industrial." That is they want to limit it to manufacturing type operations. In trying to get them to broaden their descriptions to show the full scope of Industrial Engineering we came to the conclusion that the basic problem was really the word "Industrial."
>
> A member of the AIIE Task Force was at the Dallas meeting and hoped to bring this problem of the name up with some of his friends who are active in the AIIE. He was not planning on bringing it up publicly at this time. I mention this to point out other people as well as yourself who are cognizant of this problem and through collective action perhaps a change can be made. In this study of government classifications they have a position of Management Analyst which is used primarily for office methods type studies. These are really Industrial Engineering under the definition of AIIE. Again because of the word "Industrial" meaning factory in their minds, they have a different set of classifications which really give a much better description of the Industrial Engineering function than the ones they proposed for Industrial Engineering. I think this confirms your viewpoint with a concrete illustration of the problem.

The National Industrial Conference Board Report on *Industrial Engineering Organization and Practices* (10) had the following interesting comment:

> Some believe that industrial engineering should not be regarded as a specific function such as manufacturing and sales, but as a methodology or a special body of knowledge that can be brought to bear on a wide variety of problems. Due to this concept, industrial engineering is called management engineering or administrative engineering in some companies and universities.

Finally, to conclude this portion of the paper the writer would like to offer another quotation from a letter which he received recently from a distinguished professor who is a pioneer in the field of managerial accounting:

> Thank you very much for sending me a copy of your paper on a "Unified Program of Management Controls." I am glad to see that our lines of thinking are so closely parallel. What you write about, and I hope to teach eventually, is a more specified and systematic means of doing the job of fitting facts and figures to business problems, without undue homage to extant cliques or routines. If accountants, mathematicians, engineers, statisticians and the like could forget their differences in an attempt to get broader perspective and better analyse, progress would certainly ensue.

TRENDS IN UNIVERSITY SCHOOLS OF ENGINEERING AND BUSINESS ADMINISTRATION

Traditionally university schools of business administration have been "dumping off" points for engineering schools, veritable qualitative havens from the quantitative rigors of engineering. However, the picture has been changing rapidly, at least in the best of the business administration schools. References (4) and (8) are recent studies which have put a strong spotlight on business administration programs and which have already had many salutary effects. Business administration schools are rapidly taking on the characteristics of engineering schools with the increasing introduction of quantitative methods into the curriculum. They are leading engineering schools with respect to the consideration of behavioral sciences. "Maverick-like" faculties include mathematicians, psychologists, sociologists, engineers, etc. The dominant position of the economists and accountants is rapidly weakening.

The writer predicts that in the future more and more engineering schools will drop out of the management business or at best will maintain modest programs. The line which he sees drawing sharper each day is one where engineering schools will concentrate and specialize on physical systems and business administration schools will

take over the study of man and machine systems. The environment in Industrial Engineering departments of engineering schools appears to be too limited to considerations of manufacturing operating systems, processes, materials, tooling, etc. A broad consideration of managerial decision-making processes must be made in a complete environment which includes all the functional areas of management, particularly marketing and finance and the increasingly important behavioral sciences. It is difficult to see how such historical factors as strong prejudices and the marginal status of Industrial Engineering in engineering schools can be corrected in the face of competition for resources from the important and glamorous electronic, nuclear, and space programs. The writer can still recall rather vividly his being ejected from the Dean of Engineering's Office on two occasions when he was an undergraduate student in mechanical engineering because he requested that he be allowed to take the Industrial Engineering option. The reply was, "Your grade point average is too good and you shouldn't waste your time in Industrial Engineering. You can handle the analytical courses." This was a prevalent attitude fifteen years ago. It is interesting to speculate how many potential Industrial Engineers have been "steered" into other fields because they displayed analytical prowess.

In the writer's opinion the future source of broadly educated manpower for the management engineering profession will come from business administration schools. These schools will play an increasingly important role in management education. The role of engineering schools will probably continue to be a relatively minor one unless, as at Massachusetts Institute of Technology, and Carnegie Institute of Technology, separate schools of management are set up. These schools of management are in reality schools of business administraton.

In view of the emergence of business administration schools as powerful factors in the broad education of applied management scientists or management engineers, the AIIE should re-examine and reconstitute membership requirements. The distinguished British management philosopher, Colonel Lyndall F. Urwick, in an article on the "Development of Industrial Engineering," (9) lends support to this argument with the statement:

> When the idea of applying scientific thinking to problems of business management began to make headway, businesses were faced with a serious staffing problem. By far the most numerous group of people available in industry who had had a scientific training were the engineers. It thus came about that men trained as engineers were, in fact, used on a very large variety of tasks which did not require a basic engineering training as such but for which a basic training in some branch of science and usually, some mathematical ability were an advantage. At the time, engineers were the only people available who combined these advantages with practical knowledge of business problems. Consequently, engineers were used for budgeting, salary analysis, market research, and in many other directions. And, once a profession has been employed on a new kind of development, there are always members of that profession alert to establish claims of competence—to assert, for instance, that engineering training is essential, to, if not the only conceivable form of preparation for, such tasks.

He also comments, "If it is to be effective, the engineering profession must abandon its claims to special competence in those fields to which the epithet 'engineering' has been attached as a synonym for 'scientific'." He closes his article with:

> Industrial engineers have encountered much opposition and criticism, especially from representatives of the workers. This has been healthy even where the criticism has been emotional and ill-founded. It has forced them to reexamine their techniques and to perfect their methods. International contacts and developments have compelled them to clarify their thinking and to try to perfect the standardization of their terminology. There are still many difficult and recalcitrant issues ahead. They will be settled more quickly and more easily if the engineering profession will recognize generously that science—more exact knowledge—is the private bailiwick of no man and of no group of men. It is the social heritage of humanity. A business is a society, and to its effective management (government), many disciplines must contribute. Some of them are much less developed than the underlying physical sciences on which engineering is based. Engineering enjoys the immense advantage of a long and close practical experience in industry. Industrial engineers should use those advantages not to build an empire or to establish frontiers, but to ease the work of integrating these newer disciplines into business practice. Only so can they contribute to the immense task of making the epithet "scientific" more completely applicable to all levels of management.

At this point the writer cannot resist the temptation to comment on the chameleon-like behavior which he has observed among many of the members of AIIE who have acquired some knowledge of the newer jargon and mathematical developments. Their behavior is not unlike the *nouveau riche*. They carry several badges to identify their professional activities and wear the one which best suits the occasion. Currently, it appears to be the preferred vogue to wear the "operations research" badge to connote a superior position in the order. The height of snobbery, of course, is the "management scientist" badge. The writer, who has enjoyed an educational and work experience exposure to esoteric matters is still not ashamed to wear the Industrial Engineer badge (although, as the reader may have gathered by now, he stands ready to trade it in for the "management engineer" badge!). The existence of these multiple badges is strongly suggestive of the failure of AIIE to provide a completely adequate home for all its members, and many would-be members. Perhaps a reconstituted AIIE would cause a return (in spirit) of her prodigal sons and would provide an attractive home for many newcomers.

RECOMMENDATIONS FOR LONG RUN OBJECTIVES WITH ADDITIONAL DIMENSIONS

The AIIE now has an unusual opportunity to move in the direction of doing for the management profession what the American Medical Association and the American Bar Association do for the medical and legal profession. Much can be learned from a study of these two

organizations. The AIIE is the only professional society serving the management profession which has membership standards criteria other than interest and the willingness to pay dues. The membership selection mechanism could be expanded and adapted to embrace all legitimate practitioners in all fields of applied management science, or management engineering. The definition of such revised membership standards will of course require considerable hard work and thought, but will prove to be both stimulating and expanding.

After this goal is accomplished, the task of accrediting university curricula in both engineering and business administration schools would be facilitated. The present methods of accreditation are too restrictive of progress. This function should rightfully be performed by the "new AIIE" which the writer envisions. He senses a certain inferiority complex in the attitudes and deliberations of the AIIE in its relationships (or lack of them) with the older engineering societies. This is because we fail to recognize that we are attempting to fit the new shoe, which combines the physical sciences with the social and behavioral sciences, to the old last of physical sciences. It would be better to disregard the old last and build a new one to accommodate the new shoe. Subservience is not a good alternative to constructive and positive action.

The task of helping states to develop standards for licensing would also be simplified when solons are confronted with a unified program and even more so when they know they are confronted with a well organized and universal spokesman for the management profession. This licensing mechanism would provide society with some measure of the legitimacy of practitioners. Perhaps, at that time legal means could be used to enjoin individuals and business firms from making promiscuous use of titles such as "Industrial Engineer" for jobs consisting of menial and often times degrading tasks. Most states provide licensing standards for insect exterminators. At least this modicum of protection should be provided for those people responsible for the promotion and maintenance of the health of our economy and the security of our existence. This is a most worthy objective for the "new AIIE."

The number of top management people who are currently members of AIIE could probably be counted on one's hands and toes. Certainly many could qualify for membership, even with the present membership criteria. The paucity in numbers is probably another indication of the popular image of the narrow scope of Industrial Engineering. The writer has never met an Industrial Engineer who did not privately aspire to break out of the ranks into top management. Most of those he has known who have climbed the ladder have also turned in their Industrial Engineer badge, much like the newly appointed foreman from the operator ranks who quickly sheds his toolbox and overalls. Medical doctors and attorneys wear the same badge throughout their careers. This would be another worthy objective for the "new AIIE."

The writer could continue ad infinitum expanding on the aforestated ideas and reenforcing them with quotations, experiences, etc. However, he would do so at the risk of sounding pedantic and would probably add little more to the central objective of laying down the gauntlet and providing stimulus for discussion and action to the members of AIIE. He would like to close with the thought that the Industrial Engineering profession is now in dire need of "architects and philosophers" who can give more vision, direction, and purpose to the profession. Like the older professions, we have gone through a period of craftsmanship where "master mechanics" have forged many "tools and techniques." The transition to professionalism must not be retarded by reasons of sentiment and myopia. And finally, the writer would like to say that he would appreciate hearing reactions to this article so that he can better calibrate his thoughts, and plan the presentation of specific programs of actions for consideration by those currently responsible for the leadership of our AIIE.

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Computing Optimum Shrinkage Allowances for Small Order Sizes

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IN CONCERNS that manufacture to order a problem often faced in production planning is that of determining a suitable shrinkage allowance. For each order some specified quantity of items should be produced. Because of inevitable spoilage and rejection for defects throughout the manufacturing process, more than the desired quantity of items must be started if there is to be some expectation of completing the required number of good items.

Under most conditions, the shrinkage percentage to expect over many jobs or in the long run can be predicted with some confidence. Control chart data, yield or spoilage reports, and general experience with similar runs can give good overall estimates. However, these figures can serve only as general guides in making shrinkage allowances, and for very small run quantities will be of little or no immediate assistance. The shrinkage that will be experienced on any single job depends upon chance-acting factors and will vary considerably from order to order. If items are not interchangeable between runs (as is often the case) this variation in actual quantity finished from the quantity desired may be a matter for very serious concern.

If, for example, a production run is completed and the quantity is short, it may be necessary to set up all production machines again and process a make-up rerun to bring the order up to the required size. Not only will machine setup costs be incurred again, but there will be the attendant costs for planning, routing, and dispatching the rerun and the added costs for accounting and other record keeping. If the order is held for make-up, the delay may displease the customer; if it is not, there may be added costs because part of the order leaves as a second shipment. If, on the other hand, a make-up rerun is not processed and the order is shipped short, the customer may again be displeased and also there will be less marginal income from the order. Other possible consequences of a shortage are too well known to require enumeration here.

If, to consider the other possibility, a production run is completed and the quantity of good items is more than the desired order quantity, other losses may be experienced. The overage items may be of no use to any customers and cannot be sold, either now or in the future. In this case the total variable costs incurred in their production will be lost completely. In other cases excess items may be put in storage on the possibility that a reorder of the same item may be made at a future date or that there may be some future demand as spare or replacement parts. However, if the overage is stored there will be costs of investment and space for such storage and the costs of eventual scrappage if it happens that no demand develops in the future.

The case, as outlined, is a general one in manufacturing to order. The exact nature of the various losses due to overage and the losses due to shortage and the relative importance of each will, of course, very from order to order and from company to company. The determination of shrinkage allowances is not a problem if one or more of the following conditions prevail:

1. There is virtually no spoilage or shrinkage.
2. The shrinkage for a specific job can be predicted precisely—it is not a chance matter.
3. It does not matter whether or not the exact specified order quantity is finished.
4. The production process is such that raw material can be continuously fed into it until the required number of good items is produced.

Seldom will these conditions be met when manufacturing to order. It may also be noted that the problem exists not only when producing to customer order directly, but also to meet assembly department or line parts needs when such assembly is for a specified quantity, as for example, in aircraft or special machine manufacture.

The problem, more specifically, is to determine a shrinkage allowance for each order so that the costs that are affected by the amount of this allowance are a minimum over the long run. These costs, in general, fall into three categories, two of which have previously been indicated. The first includes the costs of shortage. If shrinkage allowances are generally too small, these costs will be higher than necessary over the long run. The second category includes the costs (or losses) due to overage. Obviously, if shrinkage allowances are too large, these costs will generally be greater than necessary. The third group of costs affected by the size of the shrinkage allowance are the costs of spoilage and rejects during or after manufacture. Excessive shrinkage allowances, for example, result in larger than necessary production runs with an attendant excessive amount of spoilage and reject cost.

METHODS FOR SOLUTION

General practice has been to determine shrinkage allowances by use of judgment in terms of past experience and by "cut and try" approaches. When run sizes are large, the allowance commonly made is the quantity required to compensate exactly for the expected long run or average shrinkage. If, for example, 1000 items are ordered and 20% shrinkage is "expected," 1250 items would be started. Only under certain restricted conditions, how-

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ever, will this form of allowance computation give reasonably satisfactory allowance quantities even for large order sizes. In most cases, no recognition is made of the relative costs of overage and underage and the form of the yield frequency distribution.

A more precise solution to this problem in terms of an approximate statistical approach was made several years ago in an attempt to meet a specific manufacturing problem (4). Recently additional work on the problem has been done in an attempt to find a more precise and basic approach and one that can be adapted to a reasonably wide range of conditions. One possibility that seems to meet these objectives to some extent has been proposed (2). In this article the computational procedures are a modified form of those presented in (2).

The shrinkage allowance problem is encountered under many combinations of manufacturing and sales conditions and of cost structures. The method to be described applies when the order quantity required is fixed and must be met even if one or more reruns is required. The procedure is exact and not approximate so that it is particularly useful for cases in which the order quantity is small. In the illustrative computations it is assumed that long run shrinkage quantities will approximate a binomial distribution (a well-founded assumption almost always made in the statistical analysis of such form of loss). However, the method will apply equally well for any form of frequency distribution that may seem to best fit the case under study. In the computations to be presented it is assumed that both setup costs and the direct costs per unit of production are independent of the run size. The method does not require these assumptions; other setup and variable costs can be assumed if the run size is smaller, for example, as would be the case for make-up reruns or one may use a smaller (or larger) reject allowance. A multi-stage process is assumed with all of the items started being carried through to completion and being followed by subsequent inspections to remove all defective items. This implies the expenditure of full direct costs on all items started even though some may be spoiled and leave the floor at early stages in the production process. A simple elaboration or modification of this method could be made to allow for the fact that a portion of the shrinkage does not incur full direct unit costs before loss. In the interests of a more brief and simple discussion, this allowance factor has not been included. Finally, it will be noted that the costs of shortage are the expected costs for setup and direct labor and material required for reruns to bring the completed quantity of good items up to the specified order size. The costs of overage are the expected direct costs for allowance items started in the original run and in possible reruns less the expected value of the allowance items that are completed as good. Thus the overage cost varies directly as the amount of the overage, which seems to be the most common case in practice.

Additional work is planned for the development of procedures for other forms of the shrinkage problem. One of the more interesting of these is that of making decisions on make-up reruns at each stage in the manufacturing process for a product. After determining the shrinkage in the first stage of processing an order, for example, a decision should presumably be made on whether to continue the order in its present quantity through the next stages, or whether to hold it and process a make-up rerun through the first stage to bring the original run up to a satisfactory quantity. If more than an expected amount of spoilage has occurred at this point in the initial run, making such a catch-up rerun may prevent the need for a rerun later after more processing stages have been completed. Such decisions would depend, in part, on balancing the known costs of a new setup for that part of the process completed against the costs of setting up more of the process stages later times the probability of having to do so. If decisions of this form were to be made, the optimum initial shrinkage allowance quantity might differ from the optimum quantity to allow if the initial run were to be completed before starting a possible make-up rerun.

Another case of practical interest to be studied is that for which an order quantity tolerance is allowed by the sales contract. In some industries, for example, orders will be accepted by the customer as long as there are less than a given percentage over or under the specified order quantity. Other situations of interest include the case for which the entire run must be repeated if by chance the order is short, and the case for which the costs of underage and overage are independent of the quantity short or in excess. Another variation is the case in which a shortage in the original run may be made up by reworking, at some extra cost, part or all of the spoiled pieces. Also, plans include programming of a high-speed electronic computer for the preparation of shrinkage allowance tables for a wide range of cost relationships and yield percentages.

Approximate methods requiring fewer computations have been proposed as a means for obtaining estimates of optimum starting quantities (1) (3) (4) (5). In general, all of these methods assume a constant shortage cost either in the form of a fixed penalty or in the cost of setting up the process for one additional run to make up this shortage. The costs of overage or shortage on this and possible subsequent reruns is ignored. In addition, the assumption that the ratio of items started to good items completed is constant regardless of the starting quantity is treated in (1). Another method which assumes also that the frequency of defective items has a Poisson distribution is proposed in (5). A rigorous mathematical treatment of this problem is presented in (3). A case similar to the one presented in this article but which takes into account the costs of items spoiled in processing is considered in (2). Comparisons of the results of the simpler models with the more exact model in (2) should indicate the regions where each is most appropriate for use.

THE PROCEDURE

The symbols noted below will be used in the following discussion:

C_S = the cost of one setup.
C_V = the direct cost per unit manufactured.
V_O = the value of one excess item completed.
L = the number required to fill the order.
A = the allowance or number of excess items started in production.
D = the number of items short of completing the order at the end of a production run.
K = the number of excess good items completed.
$N = A + L$ = the total number of items started in production.
$TRC_{N,L}$ = the total relevant cost when starting N items to obtain L required good items.

Relevant Direct Production Cost $= C_V N$

Expected Overage Cost = V_O times (expected number of excess good items)

$$= V_O \sum_{k=1}^{A} kP(K = k)$$

$$= V_O \cdot E_K$$

Expected Shortage Cost = E_{SC} = (cost of being d items short) (probability of being d items short)

$$E_{SC} = \sum_{d=1}^{L-1} (C_S + C_V N - V_O E_K)_d P(D = d) + P(D = L)$$
$$\{(C_S + C_V N - V_O E_K)_L + P(D = L)[(C_S + C_V N - V_O E_K)_L + P(D = L)(\cdots)]\}$$

and

$$TRC_{N,L} = C_S + C_V N - V_O E_K + E_{SC}$$

For the illustrative computations it will be assumed that the probability, p', of an item being spoiled or found defective is .20 and that the binomial distribution for loss or shrinkage will apply. For simplicity, it has been assumed that the cost of setting up for a make-up rerun is the same as the cost of setup for the original run; likewise, that the direct costs of production are the same per item for make-up reruns as for the original run. Again for simplicity in explanation the probability of an item being spoiled is independent of run size and will be the same for a make-up rerun as for the original run. Relaxation of one or all of these assumptions could easily be made, however, at no added cost for computation time or effort.

The example is for cases in which the pertinent costs have the following relative values:

$$C_S = 30$$
$$C_V = 1$$
$$V_O = .4$$

That is, the cost for setting up for the initial and each make-up rerun is 30 times the direct cost for producing an item; the value of an item in excess of the specified order quantity is .4 of the direct cost for producing an item. Through the use of these ratios rather than actual cost figures the results will be useful for any application to which these ratios apply. Use of such ratios is not required by the method, however. Actual cost figures could be used if desired.

The determination of the optimum allowance is by a repetitive procedure. The first step, given the cost ratios and the loss distribution, is to find the optimum allowance to make when the required order quantity is only one item. This optimum allowance quantity would, of course, be used if the order size really is one item; more important, however, it will be the quantity to apply for any make-up rerun for any size order in which the original run fails by one item to supply the required order quantity. The next step is to find the optimum allowance when the order size is two. This value will be used for make-up reruns when the original or previous runs have failed by two items to produce the required quantity.

The method, it will be noted, does not give a direct solution for the allowance for a specified order quantity. It is necessary to compute costs for each allowance figure near the optimum figure and search until the minimum cost point has been found. To keep such computations at a minimum, only those costs or values that are affected by the size of the shrinkage allowance are included. The first of these is the sum of the expected setup costs. This will be the product of the cost per setup times the expected number of setups required before the specified order quantity is completed. To make this cost directly usable in rerun computations for larger order sizes, the cost of the initial setup is included. The second cost is the sum of the expected direct costs for processing the allowance items. This sum is the product of the direct cost per item times the expected number of items that will have to be processed (including those in make-up reruns) to eventually complete the order. Again, to make the cost figures directly usable in subsequent computations for larger order quantities, the direct cost for producing the order quantity itself is included as well as the direct costs incurred for the allowance items. The third element affected by the choice of shrinkage allowance amount is that of overage items. This is considered in the computations by subtracting the expected value of this overage from the expected costs for setup and operation to give the net expected cost. The expected value for overage for a specified starting quantity is the product of the value of an overage item times the expected amount of overage. This value must be something less than the direct costs for producing an item. If it is equal to or greater than production costs, no shrinkage allowance problem exists.

To determine the optimum allowance for an order size of one item, it will be necessary to find the net expected

costs if no overage is allowed (in which case runs will be made until a good item is produced), if an allowance of one is made, an allowance of two, and so on until the allowance giving the minimum net cost value is found. Suppose, for example, an allowance of one is made so that the starting quantity is two items. The probability of completing two good items (which is one over the required quantity) is .6400, of completing one good item is .3200, and of completing no good items is .0400. For this original run the net expected cost is thus:

$$1\,C_S + 2\,C_V - .6400\,V_O.$$

If no good items are completed, a make-up rerun will have to be made; the probability of this happening is .0400. If this rerun is made, two items will again be started since the shortage is one item and the computations are to determine costs when the shrinkage allowance is one. The expected costs to include will thus be:

$$.0400\,(C_S + 2\,C_V - .6400\,V_O) \quad \text{or}$$

$$.0400\,C_S + .0800\,C_V - .0256\,V_O.$$

For this make-up rerun there is a probability of .0400 that no items will be completed as good. Thus there is a probability of .0400×.0400 or .0016 of having to make a second make-up rerun. The expected costs to include for this possibility are (again, two items will be started through):

$$.0016\,(C_S + 2\,C_V - .6400\,V_O) \quad \text{or}$$

$$.0016\,C_S + .0032\,C_V - .0010\,V_O.$$

The probabilities of having to make three, four, or more make-up reruns are so small that expected costs for these possibilities can be ignored. The above costs may now be summed to give the total expect cost, which is:

$$1.0416\,C_S + 2.0832\,C_V - .6666\,V_O.$$

Similar computations may be made for other allowance quantity possibilities. The results will be:

Allowance	*Net Expected Cost*
0	$1.2499\,C_S + 1.2499\,C_V - 0V_O$
1	$1.0416\,C_S + 2.0832\,C_V - .6666\,V_O$
2	$1.0081\,C_S + 3.0243\,C_V - 1.4194\,V_O$
3	$1.0016\,C_S + 4.0064\,C_V - 2.2051\,V_O$
4	$1.0003\,C_S + 5.0015\,C_V - 3.0013\,V_O$

The net expected cost in each case may now be computed in terms of the cost values assumed for this example which were $C_S = 30$, $C_V = 1$, and $V_O = .4$. These will be found to be:

Allowance	*Net Expected Cost*
0	$1.2499 \times 30 + 1.2499 \times 1 - 0 \times .4 = 38.75$
1	$1.0416 \times 30 + 2.0832 \times 1 - .6666 \times .4 = 33.06$
2	$1.0081 \times 30 + 3.0243 \times 1 - 1.4194 \times .4 = 32.69$
3	$1.0016 \times 30 + 4.0064 \times 1 - 2.2051 \times .4 = 33.18$
4	$1.0003 \times 30 + 5.0015 \times 1 - 3.0013 \times .4 = 33.81$

Thus the optimum shrinkage allowance to make under these conditions when the order size is one is two items; a total of three items should be started through production. Likewise, this is the optimum quantity to start on any necessary make-up reruns for larger order sizes when such reruns are made to make up a shortage of one item.

Next, similar computations must be made for possible allowance quantities for an order size of two and the allowance giving minimum costs determined. Consider the computations for an allowance of two or a starting quantity of four items. The binomial probabilities for the completion of good items on the initial run are:

No. Items Good	*Probability*	*Result*
4	.4096	2 Excess Items
3	.4096	1 Excess Item
2	.1536	0 (Order exactly Filled)
1	.0256	1 Item Short
0	.0016	2 Items Short

The net expected cost for the initial run is thus:

$$C_S + 4\,C_V - (.4096 \times 2 + .4096 \times 1)V_O \quad \text{or}$$

$$C_S + 4\,C_V - 1.2288\,V_O.$$

There is a probability of .0256 of being one item short. In such a case the optimum make-up rerun size to start will be three; the expected costs for this have been determined as $1.0081\,C_S + 3.0243\,C_V - 1.4194\,V_O$. Multiplying this cost by the expectation that it will be incurred gives:

$$.0256(1.0081\,C_S + 3.0243\,C_V - 1.4194\,V_O) \quad \text{or}$$

$$.0258\,C_S + .0774\,C_V - .0363\,V_O.$$

There is also an expectation of .0016 of being two items short. In such a case the computations would be for an allowance of two since costs are being computed for this allowance size. The expected costs will be the probability of their occurrence (.0016) times the sum of the above costs. This is:

$$.0016\,(C_S + 4\,C_V - 1.2278\,V_O) + (.0258\,C_S + .0774\,C_V - .0363\,V_O)$$

or

$$.0016\,C_S + .0065\,C_V - .0020\,V_O.$$

The above covers the expected costs for this make-up rerun (including subsequent reruns if the shortage is one) for the cases in which the rerun results range from an overage of two to a shortage of one. In addition, there is a possibility of it producing no good items in which case the shortage is again two. This expectation is .0016×.0016, which is so small it can be ignored. The sum of the net expected costs is thus:

$$1.0274\,C_S + 4.0839\,C_V - 1.2671\,V_O.$$

Computations for other allowance possibilities give:

TABLE 1

Optimum Shrinkage Allowances for $p' = .20$ and for ratio $C_S : C_V : V_O = 30 : 1 : .4$

Order Size	Optimum Shrinkage Allowance
1	2
2	2
3	3
4	4
5	4
6	5
7	5
8	5
9	6
10	6

Allowance	*Net Expected Cost*
1	$1.1057\ C_S + 3.3169\ C_V - .6536\ V_O$
2	$1.0274\ C_S + 4.0839\ C_V - 1.2671\ V_O$
3	$1.0067\ C_S + 5.0209\ C_V - 2.0168\ V_O$
4	$1.0015\ C_S + 6.0045\ C_V - 2.8036\ V_O$

Again in terms of the cost values assumed for this example of 30 for C_S, 1 for C_V, and .4 for V_O, the expected net cost found for each case will be:

Allowance	*Net Expected Cost*
1	36.23
2	34.39
3	34.41
4	34.92

The low cost, it may be noted, is for an allowance of two items.

The computation procedure may be continued in the manner described to find the optimum allowance under the given conditions for order sizes of three, four, five and so on. Such computations have been made for order sizes up to ten. The results are shown in Table 1.

In continuing with computations following the results for low order sizes of 1, 2, 3 and so on, two points may be noted. First, the results for the largest order size computed and the trend for allowance sizes up to that point will indicate the approximate allowance size for the next larger order size (or any order size somewhat larger). It will not be necessary to compute costs for all possible allowance sizes to find the low cost point but only for those near the estimate; tests may be made either way until the optimum value is found. Also, a complete computation for all order sizes in sequence up is not necessary to find the allowance for some given order size. The cost figures needed from previous computations will be only those necessary to compute expected make-up rerun costs. These make-up reruns will be for relatively small quantities so after computing expected costs for order sizes for one, two, and so on up for a short range, one may go directly to computation for a considerably larger order size. Allowances for intervening order sizes may be set by interpolation if such allowances must be known. Even under this approach, however, computations become laborious if done manually for order sizes of large magnitude. The preparation of tables through use of a stored-program high-speed computer would be desirable. For this reason plans are to prepare such tables for a representative range of average proportion defective and of cost ratios.

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At the 1959 AIIE Conference and Convention, a resolution was passed designating 1961 as the Henry Laurence Gantt centennial year, during which special events commemorating this anniversary will be incorporated with its national, regional and local conferences and meetings.

The Gantt Memorial Committee was established so that the Industrial Engineer would be in a position to enhance his professional career and accomplishments by becoming familiar with the practical and technical ideas and philosophy that Mr. Gantt expounded in his writings and professional career. In order that this may be accomplished, the Gantt Memorial Committee felt that articles appearing in the Journal*—the first written by R. G. Provost—would not only serve to accomplish this, but would always be ready reference material for the AIIE members.*

The culmination of the centennial year will be the 1961 Conference and Convention which has been designated as the Gantt Memorial Conference.—L. G. Taber, *Chairman, Gantt Centennial Committee.*

The Contributions of Henry Laurence Gantt to Scientific Management

by **ROBERT G. PROVOST, SR.***

Supervisory Industrial Engineer, Head, Methods and Standards Branch, U. S. Naval Ordnance Plant, Macon, Georgia

THE IMPORTANCE of H. L. Gantt's contributions to the art and science of industrial management cannot be discussed in a few words. To select any one of his contributions alone as the most important is to slight others. Gantt is well known as a technical engineer and held many patents, some of which were important device or process patents. He is equally famous for his chart system of presenting the progress of manufacturing operations. Certainly he is well remembered as a great humanitarian who brought to the worker's place a concept of human dignity and worth.

METHODOLOGY

It is believed, however, that H. L. Gantt's greatest contribution to Industrial Engineering was in the nature of methodology rather than device or inventions. While it is almost certain that he would have achieved a degree of eminence as a technical engineer, it is to be doubted that his fame would have extended so far outside the field of a technical specialty had he not chosen Industrial Engineering as his field. As it is, he is recognized as first and foremost among the Industrial Engineers; so it must be assumed that he brought to the field some knowledge or technique that has had a lasting effect on the theory and practice of Industrial Engineering and Management.

If the famous Gantt Chart is his most important single contribution, it is because the chart is the key to the methodology which he, perhaps more than anyone else, introduced to the field of Industrial Engineering. Taylor, his teacher, introduced Gantt to the study of time and motion. Perhaps he also drew his idea of incentive as production motivation from Taylor's basic philosophy of production.

Nevertheless, as is so often the case, Taylor is on record as having recognized the greatness of his pupil's methodology. Taylor was essentially a theorist, a perfectionist. This may sound like heresy, but there is much evidence that Taylor was motivated to a great extent by a drive for perfection of the individual elements that go to make up production rather than having Gantt's willingness to sacrifice purity of form and function for something more important. It is the thesis of this discussion that H. L. Gantt's major contribution to Industrial Engineering was the recognition that the industrial situation is a dynamic system composed of a number of interlockings and subsystems which must be optimized with respect to final output only. This end cannot be achieved by viewing the manufacturing process as an aggregate of labor, capital equipment, and raw material, each a separate and distinct function.

Time has been called the essence of Gantt's system of production control. An analogy may be drawn for this system as contrasted to a piecemeal system of coordination of production elements. Gantt's system is basically a calculus of production and is applicable to a dynamic system, while Taylor's philosophy is essentially an algebraic process wherein the sum equals no more or no less than the sum of the parts, and is therefore, applicable

*The author wishes to thank Dr. Raymond Saucer for his guidance and assistance.

only to systems which can be stopped with regard to time for a static analysis. By the use of such a calculus, an interrelated set of dynamic subsystems can be analyzed as they flow without the necessity for fractionation or stopping the system when necessary for analysis. Such a dynamic analysis technique does not need the assumption that each and every factor such as labor and capital exist independently and can be controlled independently. It is obvious that in production control the shifting of value of any variable will have an effect on every other variable. It is not enough to simply train each and every worker to produce more; he must be supplied with raw material and a machine that operates satisfactorily. He must also have a certain amount of information.

OPTIMIZATION

It is not to be said that Gantt did not pay attention to details. He recognized the necessity for optimizing each and every factor. Workers must, of course, be trained and motivated. It is significant, though, that Gantt realized that each worker does not exist solely as a tender of machines, but as a human being with fears, problems, and a need for a minimal amount of security. It was this line of reasoning which led Gantt to conclude that the worker had a right to proper training and a minimal wage. It is believed by many that this was Gantt's great contribution to Industrial Engineering. Some maintain that his early papers on this subject were directly responsible for the rapid growth of worker training and the great shift in the trend to industry's training of the worker during World War I. We may grant the importance of this contribution, Gantt's humanitarian outlook; but it is possible that this is also supporting evidence for the claim that Gantt's most important contribution was a synthesis of trained workmen, busy machines, and rapid flow of materials into a complete system.

The actual process of optimization may be carried out in many different ways. Today, we are able to solve complicated logistics problems by the use of computing machinery which will handle a large number of variables expressed as a matrix of simultaneous differential equations. Mathematics has proved to be a magnificent tool in logistics, but Gantt and others of his day did not have this tool. They were forced to rely upon an intuitive analysis of a system. Such an approach may have a great deal of validity, but it does not lend itself to ease of communication with others.

INDEX OF PRODUCTION

We have said before that Gantt evidently regarded industry as a dynamic system. In order to control such a system one must be in intimate contact with each and every element, and each element must be in communication with every other element. The man possessed an uncanny ability to select an index for almost every process which would reveal the state of the system at any time with a minimum error probability. To the uninformed person, the use of an index such as the number of rivets driven on a ship or during a day as an index of ship production would seem a purely capricious choice.

But it is not so arbitrary a choice as it may seem. Shipbuilding is a complex business; many believe that the modern battleship is man's greatest engineering feat. Although World War II was marked by the advent of prefabrication to the shipbuilding industry, the linear feet of welding completed may have well been used as a production index.

This is so because a ship must grow. One does not simply build a hull and drop things into it. A timed sequence of operations must be observed. The main engines must go on their bedplates while the ship is little more than a bare keel, and pipes must go over, around, and through alleyways and bulkheads. If any one department of a shipbuilding crew is off schedule, the entire operation is delayed until the lagging crew finishes its task. Shipbuilding is a very good example of a dynamic system within industry. An automobile consists, in the main, of package assemblies put together on an assembly line, and while it is true that there is a degree of continuity in this operation, many operations can be reversed without serious consequences. In the case of shipbuilding, as each section is finished, another section can be constructed, and not before. As Gantt realized, the number of rivets driven in the hull and bulkheads is a better than fair index to the percentage completion of the ship. By counting the rivets one can analyze the day's work, or by comparing the number of rivets driven in different yards, one can determine the relative efficiency of a shipyard. Or, by counting the rivets necessary to build a hundred ships, one can keep track of the progress of the entire job on a rivets-driven schedule chart. Statistically we would say that there is a high degree of correlation between the number of rivets driven and the state of relative completion of ship.

One might submit to a clearing center a complete progress report on production. This takes days to prepare and would doubtless be out of date when read and analyzed. On the other hand, a bar graph of the number of rivets needed superimposed on a bar graph of the number driven gives an instantaneous comparison of the progress of any element of the shipbuilding process. This can be understood by the trained engineer and the pipe crew foreman with equal ease. Knowledge is vital to both.

THE GANTT CHART

Thus Gantt developed his famous chart as a method of presenting time and timing of operations. No doubt the chart is still in use in countries where Gantt's broad humanitarian principles are not allowed, but wherever production problems must be solved the Gantt Chart will be found. Oddly enough, many of Gantt's technical devices were never used; but even Gantt's modesty, which cloaks his World War I record, could not keep the greatness of the man from becoming known through the wide

use and acceptance of his charts.

Without such a chart system, the burden of coordination must, by necessity, fall directly upon the efforts of one man. For effective communication will evolve the clearing house system if left to chance development, and all too often it is the busy executive, who has other important tasks, who is left to act as information control. The social psychologist draws many interesting conclusions from the behavior of social insects. A hive of bees may consist of as many as 70,000 workers with no supervisory personnel. Yet the flow of pollen and nectar into stored honey is a smooth and orderly process. Probably the amount of honey stored versus empty area sets up a chemical reaction in the hive. In any event, each and every individual worker is cognizant in some way of the general trend of production. One person who centers this information is indispensable, and industry has no need for an indispensable man. If he is a high level executive, he must attend to other tasks.

But information is a pressing necessity and is vital to smooth functioning. By the use of the Gantt Chart, information can permeate every level of organization and is thus not susceptible to stoppage or to distortion. Executive decision is actually required only to ascertain the total production quota and the rate of production. Both these factors can be simply expressed by using a Gantt type index or by using units or multiple units as expressed against the time allotted to the total production and the daily production. But once these factors are expressed a clerk can prepare the charts. The executive board is presented with a chart every morning, along with the foreman, and perhaps the worker. If there is a stoppage of the time flow factor, it may or may not need executive action since each department can immediately recognize its contributions and act to correct them if necessary without a lengthy series of conferences or personal directives. In the perfected form the chart system usually records a breakdown by man, by machine, and by man/machine elements. Thus the growth of the final output can be instantaneously checked.

FEEDBACK

In the final analysis, a feedback is necessary to manufacturing systems. Since Gantt's major thesis was that maximum production and minimal waste are the key to manufacturing, it is by means of a constant information feedback which can be readily understood that this end is achieved. It must be done without recourse to a static system of analysis which would be out of date when computed.

The chart, therefore, serves three major functions. It is an expression of the overall planning which goes into production. If the system is adopted, it forces planning, since there can be no chart unless production quota and rate are predecided.

It provides an error-comparison feedback system. The modern development which we call "cybernetics" was in its infancy in Gantt's day; but it is not surprising that, in his far-sighted way, he designed a self-regulatory system which uses the discrepancy between an actual and projected rate and quota factor as an error signal to regulate the rate and flow of work and material in a plant. Time is always the important factor. Time lag is fatal to a complex dynamic system. Gantt evidently had an intuitive grasp of the principles which Wiener and others have later given a mathematical formulation. Gantt designed an almost complete system with little or no recourse to complex mathematics.

The chart also provides a set of short range goals. Gantt evidently knew or anticipated the fact that while long range goals may serve as motivation, such goals are more successful if they can be broken down into a series of subgoals. Gantt provides a continuum of subgoals so that each and every amount or moment of passing time has its own set of goals. This goal is constant adjustment of actual and projected rate quota factors.

The natural human tendency is to regard the major goal as important, but to regard the passing of the first large segment of time as of little importance. *In Gantt's system there is no remaining time.* The end of a day marks the end of a task; work not completed cannot be charged off against tomorrow's good time. Thus the tendency is to keep each day's production up to the mark.

In a secondary manner this relieves the pressure on the worker and lower supervisory personnel. If corrections are to be made or if time begins to run out, there is no real press for that last minute spurt which the runner calls the "finishing kick." Posting the charts also gives the worker an idea of the importance of the contribution of his and his department's work. Today we recognize this as important to the extent of trying to convince a worker of the importance of the small subassembly which he constructs for a complex airplane, and many plants have a running system of indoctrination and information for the worker.

CONCLUSIONS

It is rather evident that to Gantt the total picture was, therefore, one of optimizing a complete system which consisted of men, machines, and materials so manipulated as to secure the maximum output and that each of his major contributions, so often listed, was not an isolated fact with no common connection, but part of an overall concept of scientific management. How this concept developed in the man himself is a matter of conjecture. Although he was in many ways orderly and precise, he understood the problem of perfection in principle and in practice well enough to realize that for the Industrial Engineer, expert perfection lies in the output of the system. We find contradiction in his character. He, himself, was inclined to be somewhat dogmatic and authoritarian. Yet, he had enough insight into his own personality to realize that he sometimes thwarted his own ends; so that in his Remington Period, we find that the man under-

took to optimize his personal relations as a means of furthering the message which he had to industry. He succeeded to the extent that his personal relations with workers and subordinates began to approach the ideal which he preached but did not always practice.

It may well be that Gantt will achieve more enduring fame than Taylor, his great teacher. We are beginning to see that, instead of being merely a bright student who made some modifications on the teaching of the Master, Gantt was a prophet of industrial logistics and may well have been the man more than any other responsible for the overall theory of logistics which coordinated the efforts of industry and the military in both our great wars. It is certain that he drew much from military ideals, from "Stonewall" Jackson, perhaps from the German General Von Moeltke, who had a plan for every contingency.

In any case, it may well be that from these teachings and from his own personal characteristics the man formulated an overall theory of Industrial Engineering, which is in reality a complete philosophy. We may express it as the fact that in industry the output must be maximized by the minimization of internal friction caused by loss of communication and time. Technically, all this can be expressed by using rate/quota plotted against time as a simple but highly effective information device. Gantt was then primarily a methodologist whose great contribution was method rather than technique.

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Henry Laurence Gantt was the author of three books, the author of some 29 papers and discussions in the "Transactions of the American Society of Mechanical Engineers," and contributed around 124 articles, addresses, reports and manuscripts to various magazines during the period 1884 and 1919.

The greater number of these are in publications readily available for library research. Others—manuscripts, pamphlets, and articles in less accessible publications—have a reference to the collection where the material is on file. These are the libraries of the following individuals: Leon P. Alford, Colonel W. L. Conrad, F. D. Manning, F. J. Miller, David B. Porter, and Charles N. Underwood. The complete list is available in Leon P. Alford's book, *Henry Laurence Gantt, Leader in Industry.*

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COST CONTROL

"Measuring and Controlling Costs," Raymond I. Reul, CHEMICAL ENGINEERING, *Page 203, September 19, 1960.*

A general review of maintenance cost accounting with the standard approach in mind. This article indicates that standard Industrial Engineering approaches cannot be used blindly but must be modified to adopt them to the perculiar nature of maintenance needs. *(B. J. Grady, Ethyl Corporation)*

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"Return on Investment—Fit The Method To Your Need," Lawrance F. Bell, THE ENGINEERING ECONOMIST, *October-November, 1960.*

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The author recommends placing the safety activities under the Methods Engineering or Production Department rather than under Personnel or Industrial Relations Department. Methods engineering tools should be used in gathering information to be analyzed for conditions that make for potential injuries. *(A. L. Friedrichs, Ethyl Corporation)*

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"Snares and Delusions in Office Job Evaluation," E. E. duPont, MANAGEMENT REVIEW, *May, 1960.*

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A report prepared from interviews with key men in 80 plants—full of ideas and data for evaluating your plant's material handling practices and progress. *(B. M. Bryant, Ethyl Corporation)*

"9 Attitudes to Make a Material Handling Program Work," Frank C. Wier, MATERIAL HANDLING ENGINEERING, *page 79, October, 1960.*

MHE editor W. B. McClelland recently interviewed Mr. Wier on attitudes and procedures that are as important to a successful material handling plan as is proper equipment. *(N. E. Sparks, Ethyl Corporation)*

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"Practical Guide to Linear Programming," S. B. Smith, PURCHASING, *November 9, 1959.*

Illustrates how the techniques of Linear Programming can be applied to solving purchasing problems. Shows how this method is employed to plan the use of limited resources so that some objective—maximum profit or minimum cost—can be achieved. *(A. L. Friedrichs, Ethyl Corporation)*

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"A Rational Method of Plant Layout (Two Parts)," D. Thompson, CHEMICAL ENGINEERING, *November 30 and December 28, 1959.*

These articles on plant layout discuss (1) overall procedure and philosophy and (2) practical methods of process plant layout. *(A. L. Friedrichs, Ethyl Corporation)*

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"Systematic Layout Planning," Richard Muther, MODERN MATERIALS HANDLING, *August, 1960.*

This is the introduction to a series of articles concerning Systematic Layout Planning, a new concept for universally applicable overall procedure that tells what should be considered first, second, third—and tells at what point each of the various tools and techniques should be applied. *(N. E. Sparks, Ethyl Corporation)*

QUALITY CONTROL

"Quality Control Cuts Maintenance Errors," FACTORY, *November, 1960, page 102.*

Application of quality spot-checking to maintenance work. *(B. M. Bryant, Ethyl Corporation)*

"Management Bench Marks for Quality Control," E. M. Schrock, INDUSTRIAL QUALITY CONTROL, *February, 1960.*

Presents five steps that lead to an effective quality control program—analyzing, prescribing, organizing, promoting, and appraising results. *(A. L. Friedrichs, Eythl Corporation)*

"Reliability Concept Is Step Beyond Quality Control," STEEL, *February 29, 1960.*

Due to increasing completion which is creating a buyers market in which customers insist on high-level performance, the trend is more and more toward company installation of reliability programs to insure longer life and greater dependability for products. *(A. L. Friedrichs, Ethyl Corporation)*

SYSTEMS AND PROCEDURES

"When To Shift To Straight-Line Production," D. D. Deming, HARVARD BUSINESS REVIEW, *November-December, 1959.*

A guide for the manufacturing executive in choosing the most efficient form of production—process-controlled, straight-line manufacturing, or a combination of both. *(A. L. Friedrichs, Ethyl Corporation)*

"How To Cope With Information," F. Bello, FORTUNE, *September, 1960.*

Relates how to index and file documents by machine so that information is speedily available. Several of the methods used—mechanical, photographic, and electronic—are explained in this article. *(A. L. Friedrichs, Ethyl Corporation)*

"What's Wrong With Procedure Manuals?", Ben Katz, THE OFFICE, *October, 1960.*

Management endorses manuals, staff departments tolerate them, everyone agrees that manuals are needed—but operating people ignore them. Why?

WORK MEASUREMENT

"Memo Motion Pictures Show Way To Better Maintenance, FACTORY, *November, 1960, page 84.*

A slow movie camera can give you fast benefits, especially when you want to take a hard look at long, involved jobs that defy stop-watch analysis. *(B. M. Bryant, Ethyl Corporation)*

"Office Productivity—New Path to Profits," T. Kenny, DUN'S REVIEW AND MODERN INDUSTRY, *September, 1960.*

Results of a recent survey of 275 companies tell what today's top executives are doing to sharpen clerical operations, cut office costs, and control paper work. *(J. M. Barksdale, Ethyl Corporation)*

"What Should Ratings Rate?", A. C. MacKinney, PERSONNEL, *page 75, May-June, 1960.*

Trait rating is questioned by the author as being too complex an inferential task to expect much validity and reliability from it. Instead, he suggests that rating be confined to on-the-job performance that might be more accurately measured. *(N. E. Sparks, Ethyl Corporation)*

"Here's Work Measurement for Every Office," W. Gilbert Brooks, THE OFFICE, *September, 1960.*

With all the effective techniques available for office work measurement, there is no need for any supervisor to feel that he cannot afford this valuable tool.

"How To Make A Methods Delay Study," R. A. Boro and W. C. Cooling, THE OFFICE, *October, 1960.*

Where standards are not desired but proper manning is required this provides the answers while reducing analysis time as compared to time study and work sampling methods.

RESEARCH ABSTRACTS

July 1957—July 1958[1]

The following research abstracts represent a partial listing of research related to Industrial Engineering that was performed primarily during the July 1957 to July 1958 period as well as additional abstracts for prior periods not previously published. This information was organized by the AIIE Research Information Subcommittee from material furnished by various organizations conducting research. It does not represent an exhaustive listing, for not all research has been reported. Additional abstracts will be reported for current research on a yearly basis.

The Research Information Subcommittee has made no attempt to judge the merits of any research report. It has collected, eliminated "application" articles, and classified the reports according to the categories used by the AIIE Director of Research and the Research Committees. Reports were considered to be "application" when existing theory and/or technology was utilized to solve a specific problem without advancing a new or unique and generally applicable concept, theory, hypothesis or technique. The classification categories of each report are indicated at the start of each listing.

Copies of original research reports may be obtained by contacting directly the author or place mentioned in the abstract. Masters and doctorate theses are usually available on inter-library loan, but printed copies are not usually available. Some university libraries have facilities for supplying photostat or microfilm copies in lieu of inter-library loans, for those desiring them.

The Committee wishes to thank the organizations that have helped with this project, and to encourage the participation of all organizations in the extension of the project. Abstracts should be sent to:

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University of Birmingham
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The American Institute of Industrial Engineers has recently reorganized its classification and codification procedure for research abstracts. In this new classification system there are twelve primary research areas. The codification procedure has been broken down into a numerical coding system composed of four words. The first word consists of four digits and relates to the research area. The first two digits consist of the general research area into which the abstracts fall and the second two digits the specific area under the general area of interest. The second word consists of three digits and indicates the industry classification from which or to which the abstract is most applicable. Most abstracts will be classified under the classification of 000 since there is universal applicability for the material presented. The third word contains two digits and indicates the source from which the abstract was received. The fourth word contains two digits and indicates the place where the original research document may be obtained. All abstracts which are pub-

[1] Abstracts for prior periods not previously published are included.

lished in the future will have the four word codification as part of its identification. Some abstracts may contain more than one code as the research activity may fit into several basic research classification areas. Some organizations have punched the code and the title of the research abstracts and are using them as a ready reference for research information. It is quite easy to refer to the codification sheet and select the code numbers of interest. This information can be sorted from the card deck and all research in that particular area tabulated.

Description of Codification System

AREA		INDUSTRY		SOURCE		PUBLICATION
XXXX	:	XXX	:	XX	:	XX

Research Areas of Industrial Engineering

XXXX :

0100 *Work Measurement*
0105: Procedures Preparatory to Work Measurement
0110: Timing
0115: Measuring Operator Performance
0120: Measuring Job Difficulty
0125: Delay Allowances
0130: Machine Control and Interference Allowances
0135: Personal Allowances and Fatigue
0140: Basic Motion Standard Data
0145: Elemental Standard Data
0150: Control of Standard Times
0155: Special Labor Category Standard Times
0160: Work Sampling
0165: Macro-measurements

0200 *Methods*
0205: Non-repetitive Work Analysis Techniques
0210: Repetitive Work Analysis Techniques
0215: Basic Principles Investigation
0220: Evaluation Procedures
0225: Testing Procedures
0230: Installation Procedures

0300 *Facility Planning*
0305: Plant Layout Analysis Techniques
0310: Plant Layout Basic Principles
0315: Plant Layout Evaluation Procedures
0320: Plant Layout Testing Procedures
0325: Plant Layout Presentation Procedures
0330: Materials Handling Analysis Techniques
0335: Materials Handling Basic Principles
0340: Materials Handling Evaluation and Selection Procedures
0345: Materials Handling Testing Procedures
0350: Materials Handling Equipment Design
0355: Maintenance
0360: Plant Location
0365: Plant Design and Construction
0370: Safety

0400 *Applied Psychology*
0405: Motivation and Psychological Aspects
0410: Physiological Aspects
0415: Sociological Aspects
0420: Biomechanics
0425: Arbitration
0430: Collective Bargaining
0435: Labor
0440: Training
0445: Learning
0450: Job Evaluation
0455: Wage Incentive Plans
0460: Selection of Personnel

0500 *Engineering Economics*
0505: Replacement Theory
0510: Amortization Theory
0515: Interest Rate Concepts
0520: Decision Making

0600 *Organization Planning*
0605: Decentralization Concepts
0610: Social Scientists's Aspects
0615: Control Designs
0620: Communications
0625: Information Theory
0630: Organization Design
0635: Financial Planning

0700 *Materials Processing*
0705: Tool Engineering
0720: Process Research
0730: Mechanization
0740: Inspection
0745: Product Research

0800 *Production Planning and Control*
0805: Inventory Control
0810: Forecasting
0815: Scheduling
0820: Dispatching
0825: Routing
0830: Packaging
0840: Analysis and Measurement Techniques for Planning and Control
0845: Receiving and Shipping
0850: Stockkeeping and Warehousing
0855: Control Models and Simulation

0900 *Data Processing Systems Design*
0905: Digital Computers
0910: Analog Computers
0915: Accounting Equipment
0920: Desk Equipment
0925: Auxiliary Equipment
0930: Analysis Techniques

1000 *Applied Mathematics*
1005: Mathematical Programming
1010: Waiting Line Theory
1015: Simulation Concepts
1020: Game Theory
1025: Monte Carlo Concepts
1030: Probability Theory
1035: Sampling Concepts
1040: Acceptance Sampling
1045: Quality Control Techniques

1100 *Costs and Cost Control*
1105: Accounting Concepts
1110: Inspection
1115: Budgets
1120: Control Procedures
1125: Purchasing
1200 *Industrial Engineering Education*
1205: Curricula Undergraduate
1210: Curricula Graduate
1215: Testing
1220: Education attainment

INDUSTRY AND BUSINESS CLASSIFICATION

: XXX:

:000: General or Non-classifiable
:100: Agricultural, forestry and fisheries
:200: Mining
:300: Contract construction
:400: Manufacturing
:500: Transportation, communication, electric, gas and sanitary services
:600: Wholesale and retail
:700: Finance, insurance and real estate
:800: Services
:900: Government

SOURCE

: XX :

:10: Unknown
:20: College or University Masters Thesis
:30: Colege or University Doctorate Thesis
:40: Industrial
:50: Government
:60: Foundation
:70: College or University Bachelor's Thesis
:80: College or University Research—no degree fulfillment

PUBLICATION DATA

: XX

:10 Unpublished
:20 University Library
:30 Technical Journal
:40 Trade Journal
:50 Book
:60 Pamphlet
:70 Industrial Library
:80 Foundation Library

0115:000:20:20. An Analysis of the Differences in Time Study Rating from Films of Operations and the Actual Operator; *Nadler, Gerald; June, 1946; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Four jobs were presented on film at their different speeds and then an operator performed the same jobs at as nearly the same speeds as shown on the films as possible. The results showed a tendency for the actual operator to be rated more consistently and accurately than the films of the operations, with the average ratings being much the same in both cases.

0140:000:20:20. An Analysis of Synthetic Time Systems; *Doulet, Dan C.; August, 1943; Department of Industrial Engineering, University of Tennessee, Knoxville, Tennessee.*

The study describes in detail the four major contemporary synthetic time systems used to measure manual work. These systems are: Motion Time Analysis, Work-Factor, Methods-Time Measurement, Basic Motion Timestudy. Examples are included to illustrate how each system is applied. These examples also illustrate time value comparisons of the four synthetic time systems.

0155:800:30:20 and 0205:800:30:20. An application of Management Engineering to Non-Repetitive Work—Hospital Nursing; *Hudson, W. R.; August, 1954; State University of Iowa, Iowa City, Iowa.*

A systematic investigation to determine by experiment the extent to which the usual conventional Industrial Engineering techniques are applicable to a class of non-repetitive, non-industrial work. While none of the attempted techniques were found inapplicable the more detailed work measurement techniques appear to be relatively uneconomical. It appears more practical to state performance time for overall groups of tasks, and it is demonstrated that this can be done.

0110:000:20:20. An Audio Timing Device for Use in Time Study; *Lenthe, Charles, F.; August, 1952; Engineering Library, State University of Iowa, Iowa City, Iowa.*

Short duration audible tones spaced at intervals of 1/100th minute were imposed on a tape concurrently with the time study observer's description of element break points. A known interval between pips constitutes the basis for timing each element. A film study of several factory operations comprising a total of 288 individual elements indicates that the audio timing technique gives promise of being a technique containing less error than decimal stop watch or memo-motion film.

0110:000:20:20. An Evaluation of Memo-Motion Study for Industrial Usage; *Dudek, Richard Albert; February, 1951; Engineering Library, State University of Iowa, Iowa City, Iowa.*

Comparison of time recording accuracy of stop watch, decimal minute photography, and micromotion photography.

0115:000:20:20. An Evaluation of Two Time Study Rating Aids; *Lehrer, Robert Nathaniel; February, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

(1) Proposal of establishment of standard time film for projection with a film to be rated. (2) Matching of standard film with film to be rated by varying the speed of projection of the standard film.

0155:000:30:20 and 0160:000:30:20 and 0205:000:30:20. An Investigation of Problems in Attempting to Extend the Use of Work Measurement Concepts—Administrative Work; *Hilpert, John M.; February, 1956; Engineering Library, State University of Iowa, Iowa City, Iowa.*

The use of presently available techniques to measure administrative work represented by material control analyst in an industrial plant. This work is essentially non-repetitive, non-standard and non-manual. Existing techniques useful only for manual, repetitive and standardized work.

0110:000:20:20. An Investigation of the Suitability of a Recording Timer for Factory Operation Time Studies: *Wilson, Kenneth D.; February, 1955; Engineering Library, State University of Iowa, Iowa City, Iowa.*

Comparison of accuracy obtained in recording times using mechanical recorder as opposed to stop watch study and micromotion study.

0115:000:20:20 and 0120:000:20:20 and 0410:000:20:20. A Metabolic Investigation of the Effect of Pace on the Weight Handled Secondary Adjustment; *Barany, James W.; January, 1958; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Four subjects were used to test the null hypothesis that the proportionality of the effect of job difficulty, ascertained by the physiological cost of moving a five and ten pound weight, remains constant for speeds of performance of 60, 80, 100, and 120 percent of normal. The main effect due to pace was not statistically significant; however, there was very strong evidence, α less than one percent, that job difficulty does not remain constant for the four paces for a particular individual.

0140:000:20:20. The Preliminary Validation of Fundamental Elemental Time Data; *Podlaha, Otto Clarence; August, 1951; Engineering Library, State University of Iowa, Iowa City, Iowa.*

The comparisons of predetermined elemental time data for

hand motions assigned by a proprietary system with the laboratory time values obtained in previous research studies in motion and time study. This study tended to substantiate in general the theory of the predetermined time system but no conclusions could be drawn as to the general accuracy. Transport times and the increasing time due to control were also generally substantiated. It pointed out the need for further basic research and direction that it should follow.

0115:000:70:20 and 0405:000:70:20. Statistical Analysis of Performance Rating; *O'Connell, Daniel G., and Ney, Richard, M.; 1958; Engineering Library, Engineering Hall, University of Pittsburgh, Pittsburgh 13, Pennsylvania.*

This investigation was performed to evaluate the relationship between time study observers' performance rating ability and their experience and familiarity with the operations being rated. The observations of a group of raters were used collectively and analyzed to determine if there were significant differences between these groups. Various statistical methods were applied to the data to determine the significance.

0445:000:20:20. A Study of Learning Curves of Industrial Manual Operations; *Aroef, Matthias; 1958; Engineering Library, Cornell University, Ithaca, New York.*

This thesis concerns the first phase of a continuing project directed to development of a satisfactory method of predicting operator learning time. This report covers mainly the bibliographical and project planning phases. Some data and data analysis are included, but not a sufficient amount to permit development of the desired predictive device.

0140:000:20:20. A Study of Pre-Determined Motion-Time Standards; *Stanton, William, L.; June, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

In this study, five methods of determining motion-time standards were compared for thirteen work operations. Films of the operations, together with samples of the parts used in them, were sent to men experienced in setting such standard times. Analysis of the statistical data led to conclusions as to the reliability and consistency of the five methods with respect to each other.

0110:000:20:20 and 0120:000:20:20. Time Allowances for the Handling of Weights for Use in Stop Watch Time Studies; *Solberg, Robert Burton; June, 1946; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Determination of allowances to be added to base time for movements involving weight, using the Mundel Rating System.

0115:000:20:20 and 0410:000:20:20. The Use of Heart Rate as a Pace Predictor; *Bachman, John Logan; August, 1957; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

In an experimental setup, heart beats were measured on a standard task and prediction therefrom on performance rating for unrelated tasks were computed. Prediction ranges are too wide to be of practical value.

0215:000:20:20. Development of Principles of Motion Economy Applicable to Multi-Man Operations; *Hauser, James J.; August, 1946; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Multi-man activities were studied under both laboratory and industrial conditions. The results of the experiment are five principles of motion economy applicable to multi-man operations, especially under conditions where only hand tools are used.

0215:000:20:20 and 0705:000:20:20. Motion Study in Tool Design, a Survey of Eastern Iowa; *Clarke, Robert E.; June, 1954; Engineering Library, State University of Iowa, Iowa City, Iowa.*

A survey of current practice in tool design departments relative to motion economy principles and a consideration of the need for training programs. The use of motion economy principles in a formal manner and standard time data had not generally been accepted and practiced. A need and desire for training in this area were demonstrated.

0215:000:30:20 and 0410:000:30:20 and 0420:000:30:20. Physiological Evaluation of Selected Principles of Motion Economy; *Nichols, D. Edward; January, 1958; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The purpose of this research was to appraise several of the principles of motion economy with the use of a physiological measure of the human cost of doing work. The physiological criterion used resulted in endorsement of the three motion economy principles which have to do with the simultaneous and symmetrical hand motions.

0225:000:20:20 and 0445:000:20:20. A Statistical Method for Auditing Standard Job Conditions; *Adams, Robert M.; June, 1951; Engineering Library, State University of Iowa, Iowa City, Iowa.*

A study of the utility of control charting and distribution charting techniques for the prediction of changes in job methods. This study pointed out some significant relationships between the shape of the distribution curve and the state of the wage incentive administration.

0330:000:20:20 and 0520:000:20:20 and 1120:000:20:20. An Analytical Approach to the Warehousing Problem; *Gross, Donald; February, 1959; Cornell University Library, Ithaca, New York.*

An analytical expression for storage costs is developed and refined for (1) a warehouse which uses fork-lift trucks and (2) a warehouse which uses a drag-line and fork-lift trucks. Units of throughput used are in cubic feet. Factors are used to describe load and operating conditions. Certain parameters of the warehouse are analyzed by means of the mathematical model.

0300:800:50:60 and 0410:800:50:60. Comparative Evaluation of Hospital Beds; *Ganong, Warren L.; Schroedel, Karl B.; Kovacs Alberta R.; and DeLeo, Emil A.; March, 1959. This investigation (GN-4792 is sponsored by the Division of Nursing Resources of the United States Public Health Service; Hospital Bed Project, Department of Industrial Engineering, Room 1054 Health, Professions Building, 3550 Terrace Street, University of Pittsburgh, Pittsburgh 13, Pennsylvania.*

This progress report summarizes additional steps taken and results achieved toward the objective of developing criteria for hospital beds which will provide the optimum in patient care, comfort and safety; will best serve as an effective tool for hospital personnel; and will be practical from the standpoint of hospital economics. The report includes: a summary of medical opinions concerning spring positions and dimensions; a method for categorizing surgical patients according to their nursing care needs; a preliminary motion analysis of nursing procedures; the results of a pilot study to obtain physical measurements of hospital personnel; and a digest of characteristics of currently available hospital beds.

0300:800:50:60. Comparative Evaluation of Hospital Beds; *Ganong, Warren L.; and Smalley, Harold E.; 1958; Interim Report, Research Contract; University of Pittsburgh, 1055 Health Professions Building, Pittsburgh 13, Pennsylvania.*

Past research has covered the use and types of present features with conclusions as to what features are desirable, are used and are

needed. An analysis of nursing procedures with the bed and how these effect the design. Some investigation of mechanization of patient care. Present research is investigating the correct dimensions of the bed, the desirability of various spring positions and will in the future evaluate a proto-type bed, as suggested by research, against the standard beds now available.

0300:400:40:40 and 0730:400:40:40. Establishing Electrical Standards for Machinery; *Hyle, M. J.; April 1959; Western Electric Co., Point Breeze Works;* **Plant Engineering.**

Traces the development of a standard for electrical circuitry required by the rapidly increasing use of complex electrical controls in manufacturing facilities.

0720:400:20:20. An Experimental Design to Measure Dynamic Compressive Punch Forces in a Stamping Operation; *Schafer, James Dodge; August, 1957; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Significant factors affecting the minimum compressive punch force necessary to perform a stamping operation are: depth of penetration, punch area, stroke speed, variation in commercial heat treating between lots, and slight variation in chemical analysis. Application of the analysis of variance technique disclosed the above factors significant. Strain gages, strain gage amplifier, and Twin-Viso recorder were used to obtain and record punch force.

0335:200:60:80 and 0335:300:60:80 and 0335:400:60:80. Gravity Flow of Bulk Materials; *LaForge, R. M. and Hatcher, S. T.; June, 1958; A.S.M.E. Materials Handling Research Committee, Dept. of Industrial Engineering, University of Tennessee, Knoxville, Tennessee.*

Measurements of the gravity flow of spherical particles (.015"-1.0" diameter) through round orifices are the basis for a new formula for the rate of flow which is independent of the weight or specific gravity of the material. Previous investigations set flow as the cube or the 5/2 power of the orifice diameter, but this report indicates that the exponent of the orifice diameter varies with the particle size (from 2.0 to perhaps 3.5).

0340:400:40:40. How to Evaluate In-Plant Containers; *Schafer, N. G.; Western Electric Company Allentown Works; February, 1959;* **Material Handling Engineering.**

Presents a graphical technique for weighing tote pan selection factors, including the reactions of the several functional groups through which the containers pass in use.

0300:400:40:40 and 0405:400:40:40 and 0410:400:40:40. How to Reduce Machine Noise; *Smith, D. B.; Western Electric Company, Headquarters, September, 1958;* **American Machinst.**

Discusses methods of limiting the noise emitted by production machinery.

0300:400:40:40 and 0500:400:40:40. Industrial Lighting; *Arsnow, E. G.; Product Planning Engineer, Western Electric Company, Merrimack Valley Works;* **Plant Engineering;** *January, 1958.*

The economic analysis of plant lighting systems. Relates installation, operating and maintenance considerations to the selection of fixtures, lamps and power characteristics. The author has previously published "Supplementary Lighting" in *Plant Engineering* for September, 1956.

0300:400:20:20 and 0705:400:20:20. The Influence of Armament Production on the Development of Machine Tools and Production Methods for Peacetime Goods; *Dizer, Horn, Thomas, Jr.; June 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Armament production was instrumental in the early development of machine tools. During the past 80 years, most machine tools have been developed as a result of the influence and need of the auto industries, appliances, sewing machines, and other industries. Information for the thesis was obtained through a study of the literature and communications with machine tool and gun companies.

0720:400:20:20. An Investigation to Determine the Optimum Machining Conditions for Electric Spark Machining Processes; *McDowell, Richard, W.; May, 1958; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Five different shaped electrodes were tested to determine the effects of electrode shape on metal removal rate. Results showed that optimum removal rate is obtained with an electrode which is designed to aid in the evacuation of foreign particles which collect during the cutting process.

0340:200:20:20 and 0340:500:20:20 and 0350:200:20:20 and 0350:500:20:20. Large-Scale-Coal Handling a Comparison of Existing Installation with a Proposed Device Using Buoyant Forces; *Lawson, Emmett Willmore; March, 1955; University of Tennessee, Department of Industrial Engineering, Knoxville, Tennessee.*

This thesis involves studies of large coal-handling facilities and a description of a barge-unloading rig. The barge-unloading rig, proposed by the writer, consists of a large installation capable of dumping the contents of a coal barge, utilizing the force of buoyancy. A change of water level in a barge dock basin results in adequate movement to bring about the discharge of the barge contents into a reclaiming hopper.

0340:000:20:20. Material Handling in Industry; *Elrod, John T.; June, 1939; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The results of a survey of industrial organizations are tabulated and discussed at length after a description of material handling equipment and an analysis of the factors connected with such equipment.

0730:400:40:40. Mechanized Assembly of Transistors; *Shafer, R. C.; Western Electric Company, Allentown Works; November, 1958;* **Tooling and Production.**

Aimed at a high-volume, low-cost production, the development of a transistor assembly machine is an important forward step in semi-conductor technology.

0365:000:40:40. Methods of Glare Reduction; *Derosa, S. T.; Western Electric Company, Headquarters, Distribution Planning Engineering; April, 1959;* **Plant Engineering.**

Considers the economics of various techniques for reducing window glare in occupied areas.

0705:400:20:20. A New Manufacturing Method for a Marine Diesel Engine Coolant Pump; *Beebe, Robert Lyon; February, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

The object was to set up a new manufacturing method for the coolant pump. A new method was developed with important changes made in the large parts and the comparison between the new and old method showed significant savings with the new method.

0370:400:40:40. Occupational Hazards; *Grigat, W. A.; Western Electric Company, Kearny Works; March, 1959;* **Occupational Hazards.**

The safe use of acids, solvents, and poisonous materials required in plating operations demands a program to recognize hazards and hold them to a minimum, while providing protection for operating personnel.

0305:000:20:20. Optimum Transportation Cost as a Factor in Plant Layout; *Freeman, Jack; June, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis seeks to provide a guide for the plant layout engineer in the form of an ideal set of relationships based upon optimum cost of internal transportation for non-continuous manufacturing conditions. Current practice is studied to disclose the weak points. These weak points indicate the development necessary to the evolution of the required guide.

0830:000:20:20. Packaging Engineering; *Gundelfinger, Peter Frank; June, 1950; Main Library, Cornell University, Ithaca, New York.*

A brief history of packaging is given and some of the importance of packaging is discussed. Three different types of packaging problems are analyzed and studied. These are case studies with data taken directly from real life industrial situations. No theories are developed, but some approaches to the packaging problem are discussed from an engineering point of view.

0330:400:40:40 and 0845:400:40:40. Pallets for Interplant Shipment; *Wiltrakis, J. E.; Westren Electric Company, Kearny Works; November, 1958;* **Materials Handling Engineering.**

A systems engineering approach considers the many factors connected with interplant shipping of pallet loads.

0340:000:30:20. Pneumatic Conveying in Small Pipes; *Foecking, Norbert J.; September, 1950; Library, Cornell University, Ithaca, New York.*

The investigation studied the friction losses found in the flow of mixtures of solids and air through horizontal and vertical pipes. Tests were conducted with ½ in., 1 in., and 2 in. pipes at velocities of 35, 50, 65, and 80 feet per second with material densities varying from 79 to 457 lbs./cu. ft. The particle sizes varied in diameter from .0038 to .0158 inches. Conclusions drawn from the research differ markedly from published values.

0330:000:20:20. A Procedure for Analyzing the Problem of Materials Handling; *Gibson, Walter Claude; June, 1949; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

A procedure for analyzing the problem of materials handling in all of its phases throughout the entire production cycle is established in this thesis. A survey of current literature was made and several charts covering available materials handling equipment are included. Also presented is a four step plan for securing the data necessary for a materials handling analysis.

0300:400:20:20 and 0300:900:20:20 and 0720:900:20:20. Production of Special Shell Lathes; *Lucas, Ernest L.; August, 1939; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis deals with the problem of procurement of special duty machine tools by U. S. Army supply branches in the event of a national emergency. The idea of fabrication of two standard types of lathes from steel plates, channels, I-beams and seamless tubing is shown to be practical, economical, and to provide single purpose lathes comparable to those being manufactured from castings and special parts.

0720:400:20:20. Punching and Stripping Forces in a Blanking Operation at Varying Strokes per Minute; *Collins, James D.; May, 1958; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Various factors affecting punching and stripping forces were analyzed. It was found that speed, vibrations, strokes per minute, and die clearance all affect punching forces, while strokes per minute have a significant effect on stripping forces.

0340:000:20:20. A Quantitative Approach to the Selection of Material Handling Equipment; *Collier, James A.; August, 1957; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis is an attempt to quantify and analyze some of the variables which enter into the selection of materials handling equipment for jobs or systems. The model offers a new approach to problems involving unit decision where the entire unit must either be accepted or rejected.

0705:400:40:40. Reed Coining Goes through Interesting Die Development; *Nelson, E. W.; Western Electric Company, Allentown Works; January, 1959;* **Machinery.**

Traces the development of tooling which compresses a round iron-nickel wire into a flat reed which meets close tolerances for flatness, parallelism, and freedom from twist.

0305:800:30:20. A Scientific Basis for the Design of Institution Kitchens; *Thomas, Orpha M. H.; June, 1948; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Applying industrial methods, a procedure is established as indicated in the title. This includes the development of criteria for ascertaining the pieces of equipment needed for institution kitchens in connection with the production demands placed upon that equipment, and for the establishment of the arrangement of such equipment that will result in the maximum output with a minimum amount of labor.

0300:000:40:40. Selecting Battery Charging Methods; *Kimmel, F. E.; Western Electric Company, Hawthorne Works; July, 1958;* **Modern Materials Handling.**

Describes the battery charging equipment and techniques designed to insure optimum performance of a large fleet of industrial electric trucks.

0305:000:20:20 and 0340:000:20:20. Selection of Installations for Metal Cleaning, with Emphasis on Materials Handling; *Van Court, Donald Peter; June, 1951; Library, Cornell University, Ithaca, New York.*

A discussion of parts cleaning is given. The various reasons for cleaning, types of soils to be removed, method of removal, and sequences of removal are discussed. Types of installations are given with handling methods applicable, containers involved, and associated problems of plant design and layout are discussed. Principles discussed and developed are then demonstrated by using a sample problem and designing an appropriate installation.

0335:000:20:20. A Study of Certain Factors Affecting Gravity Flow of Bulk Materials from Bins; *Delionback, Leon Melvin; December, 1955; Department of Industrial Engineering, University of Tennessee, Knoxville, Tennessee.*

The gravity flow of solid particles in confined areas was found to be influenced by several factors. These factors are: (1) size, range of sizes, and dispersion of sizes of the particles; (2) the shape of the particles; (3) the inherent characteristics of the derivative materials; (4) the angle of internal friction of particles in a granular mass; (5) moisture content; (6) the angle of internal friction as related to the sides of the bins, hoppers, and chutes;

(7) inter-particle attraction; (8) the percentage of fines; (9) the bulk density and strength. The intent of this study was to apply knowledge of these factors to the design of bins, hoppers, and chutes.

0845:400:40:40. Switching: New Tool in Order Picking; *Funk, E. A.; Department Chief, Western Electric Company, Distribution Planning Engineering, New York, January, 1958;* **Modern Materials Handling.**

Describes the operation of a conveyor system designed to speed the filling of telephone company orders at Western Electric distributing houses. Mr. Funk has applied for a patent in connection with this development.

0455:400:20:20. Applying Incentive Wage Plan to Inspection and High Quality Production; *Powers, Robert B.; September, 1950; Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.*

A reference search and analysis of use of incentives in high quality production and inspection operations. Conclusions are that incentive wage plans can be effectively utilized in such applications, but only with modern statistical quality control and time study techniques and that past failures are in general due to failures in quality management.

0115:000:30:20 and 0410:000:30:20. Design and Initial Evaluation of a Force Platform for Measuring Human Work; *Green, J. M.; June, 1957; State University of Iowa, Engineering Library, Iowa City, Iowa.*

The design of a suitable platform is detailed. The time-force trace from the platform is compared with (a) known foot-pound content of the task (b) oxygen consumption (c) pulse rate. It is concluded that (1) the platform cannot measure "work" (physical definition) because it does not measure distance (2) a modification of the platform trace, called "force-frequency" does correlate well with known foot-pound content. Usefulness of platform in "static" work or small effort dynamic work is not evaluated.

0410:000:50:60. The Display of Warning Information; *Dunlap & Associates, Inc., Stamford, Connecticut; April, 1958; Tech. Rpt. 58-2 prepared under Office of Naval Research Contract Nonr-1076(00) prepared for Douglas Aircraft Company, Inc., El Segundo Division, El Segundo, California.*

This report summarizes most of the literature relating to visual, auditory and other types of warning displays. The need for master warning systems is discussed as well as the importance of using more than one type of signal to insure that it will not be missed by the pilot operating under a wide variety of conditions.

0405:000:20:20 and 0630:000:20:20. An Employment Problem and a Suggested Solution; *Von Bernuth, William S.; June, 1924; Inter-Library Loan Service; Purdue University, Lafayette, Indiana.*

The old "hire and fire" method of employment is critically examined and an industrial relations department is proposed to handle employment procedures. The functions of this department are given in a list of ten items. Each is examined in the thesis.

0440:000:30:20. Management Training Films—Their Design, Production, and Application; *George, Claude S. and Parden, Robert J.; June, 1953; Engineering Library, State University of Iowa, Iowa City, Iowa.*

A literature study of the factors influencing the effectiveness of motion picture training films and the actual production of a training film for "process charts" and "man-machine charts."

0455:000:30:20. The Management of Wage Incentives; *Kilbridge, Maurice D.; February, 1954; Engineering Library, State University of Iowa, Iowa City, Iowa.*

Study of the factors contributing to the success or failure of wage incentive plans. Proposal and testing of a statistical method for evaluating effectiveness of such plans.

0410:500:50:60. Operational Readout Requirements; *Dunlap & Associates, Inc., Stamford, Connecticut, Tech. Rpt. No. 121-58-3—Prepared under Office of Naval Research Contract Nonr 1076(00), for Douglas Aircraft Company, Inc., El Segundo Division, El Segundo, California.*

The requirements of operational pilots for desirable scale ranges and readability for quantitative information are summarized. This information was developed after extensive, interviews with Naval aviators, and will be of use in specifying the requirements for advanced instrument displays.

0410:000:50:30. Some Survival Aspects of Space Travel; *Mayo, Alfred M.; May, 1957; Equipment & Safety Research, Douglas Aircraft Company, Inc., El Segundo Division, 827 Lapham Street, El Segundo, California.* **The Journal of Aviation Medicine,** *Vol. 28, No. 5, October, 1957.*

Factors dictating the design of space vehicle are enumerated. Survival problems resulting from the space environment are discussed. Recommendations are made with reference to the incorporation of features designed to minimize the anticipated environmental hazards.

0450:000:20:20. A Test of Certain Fundamental Assumptions in Job Evaluation Systems; *Parikh, Arvind C.; January, 1958; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Two of the fundamental assumptions regarding time and location were tested for validity under actual conditions. Correlation between the best estimates of true ranking for all jobs for two periods was observed. Author concludes that the assumption regarding time was found to be valid and not valid regarding location. Coefficient of correlation between two periods of true ranking was high.

0435:000:20:20. Trends in Labor Relations; *Field, R. W.; February, 1947; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

Survey of trend in labor relations with emphasis on union management agreements.

0505:000:20:20. Capital Equipment Replacement Policy; *Miller, Ervin F.; 1959; University of Wisconsin, Thesis Library, Madison, Wisconsin.*

The objective of the thesis is to develop a short analysis form to be used by Shop Supervision in searching for possible equipment replacement opportunities. The short analysis form has the advantage of helping to bring to Top Management's attention all equipment replacement opportunities that may exist.

0405:000:20:20. Comparison of the Human Element in Civilian and Military Administration; *Brewer, Clayton C.; August, 1954; University of Tennessee, Department of Industrial Engineering, Knoxville, Tennessee.*

The purpose of this study is threefold; (1) to compare the human element in civilian and military administration, and in doing so, (2) to bring about a better understanding between military and civilian personnel of the differences that exist in attitudes and in methods, and (3) to enable each to benefit by the adoption of the better methods of the other or by the adoption of more tolerant attitudes.

0625:000:30:20 and 0630:000:30:20. A Concept of Organization and Management; *Lohmann, Melvin R.; February, 1964; State University of Iowa, Engineering Library, Iowa City, Iowa.*

A philosophical attempt to accomplish: (1) the construction of useful concepts of organization and management; (2) the creation of a vocabulary of words with extensional meanings; and (3) the reduction of the complex art of management to a relatively few fundamentals to facilitate their application.

0905:000:80:30 and 1030:000:80:30 and 1045:000:80:30. Computer Methods for Estimating Weibull Parameters in Reliability Studies; *Kao, John H. K.; Cornell Research Report EE344 (Technical Report No. 34) August, 1957; School of Electrical Engineering, Cornell University, Ithaca, New York; published in* **IRE Transactions on Reliability and Quality Control,** *PGROC-13, July, 1958, pp. 15-22.*

This report covers four methods of estimating parameters of a Weibull distribution from the failure data. Three of the four methods are particularly suited on modern digital computers. As an illustration, the failure data for five lots of some 400 electron tubes are treated by all four methods of estimation. Comparisons are made on the results and merits of these methods.

1030:000:50:30 and 1045:000:50:30. The Design and Analysis of Life-Testing Experiments; *Kao, John H.; February, 1958, U. S. Signal Corps Contract DA36-039-sc-64646; Department of Industrial Engineering, Cornell University, Ithaca, New York; Published in 1958* **ASQC Middle Atlantic Conference Transactions,** *pp. 217-233, ASQC, Inc., Milwaukee 3, Wisconsin.*

Life quality characteristics are defined. Weibull Probability paper is explained. Designs of life-testing experiments with various objectives are sketched. From these designs, trade-off curves and surfaces are more rationally obtained.

1030:000:50:60 and 1045:000:50:60. Determination of Vacuum Tube Catastrophic and Wear-Out Failure Properties from Life-Testing Data; *Dalman, G. C., and Kao, J. H. K.; September, 1958; U.S. Signal Corps Contract DA36-039-sc-64646; Phillips Hall, Cornell University, Ithaca, New York.*

The notions of composite and mixed distributions are introduced. A 2-component composite and a 2-subpopulation mixed Weibull distribution are found to be appropriate in characterizing the failure data of electron tubes. Data from Cornell experiment and from General Electric Company were used to demonstrate the methods proposed in this report.

1045:000:20:20. Job-Lot Control Chart for Variables; *McCurry, Charles Eugene; June, 1954; University of Tennessee, Department of Industrial Engineering, Knoxville, Tennessee.*

The purpose of the study was to develop a control chart for variables, which could be used for job-lot production in the same manner that conventional average and range charts are used for the control of quality in mass production. The study consisted of developing a system for converting dimensional units to pure numbers, thereby, eliminating the identity of individual dimensions. This made it possible to plot more than one dimension or part on the same chart, and to compute limits in terms of the pure numbers.

1035:000:400:20. A Multi-Level ACQL Sampling Plan with Weighted Defect Classification; *Stephens, K., Western Electric Company, Allentown Works; Fall, 1958; Rutgers University.*

Describes a final product inspection procedure which checks conformance with Bell System standards.

1030:000:80:30 and 1045:000:80:30. Quantifying the Life Quality of Electron Tubes with the Weibull Distribution; *Kao, John H. K.; November 30, 1955; Cornell Research Report EE271 (Technical Report No. 26) Cornell University, School of Electrical Engineering, Cornell University, Ithaca, New York; Published with modifications and addition of examples under another title: A New-Life-Quality Measure for Electron Tubes,* ***IRE Transactions on Reliability and Quality Control,*** *PGROC-7, April, 1958, pp. 1-11.*

A parametric measure based upon a Weibull distribution is proposed to replace the "credit-hour" measure specified in the Military Specification MIL-E-I. Fixed shape parameter is assumed.

1030:000:20:20 and 1040:000:20:20. A Two Sample Decision Procedure for Ranking Means of Normal Populations with a Common Known Variance; *Cohen, Donald S.; June, 1959; Department of Industrial and Engineering Administration, Cornell University, Ithaca, New York.*

Let $\mu_1 \leqq \mu_2 \leqq \ldots \leqq \mu_k$ be the means of k independent normal population with a common known variance. A two stage procedure is given which guarantees Pr [correct selection/$\mu_k - \mu_{k-1} \geqq \delta^*$] $\geqq P^*$, where $o < \delta^* < \infty$ and $\frac{1}{k} < P^* < 1$ are specified by the experimenter, whose goal is to select the population associated with μ_k. The procedure has the advantage that if $\mu_k - \mu_{k-1}$ is large, the decision is made at the end of the first stage with high probability; thus savings in average sample number are achieved.

1030:000:50:30 and 1045:000:50:30. The Weibull Distribution in Life-Testing of Electron Tubes; *Kao, John H. K.; December, 1955; Work partially supported by the U.S. Signal Corps Contract DA36-039-sc-64646, Department of Industrial Engineering, Upson Hall, Cornell University, Ithaca, New York; abstract published in the* **Journal of American Statistical Association** *Vol. 51, No. 275 (Sept. 1956) p. 514.*

The properties of Weibull distribution are studied. The maximum likelihood estimates for the parameters for truncated data are found. Experience with the failure of more than two thousand electron tubes are fitted to Weibull distributions with good agreement. Small-sample testing procedure for the scale parameter in the case of fixed shape parameter is given.

1030:000:80:20 and 1040:000:80:20. The Weibull Distribution in Reliability Studies; *Kao, John H. K.; Cornell Research Report EE343 (Technical Report No. 33), August, 1957; School of Electrical Engineering, Cornell University, Ithaca, New York.*

As a result of the statistical analysis of failure data, it is possible now to devise a rational set of acceptance criteria for components under reliability studies such that some of the desirable characteristics can be guaranteed with pre-assigned limits. This report demonstrates these criteria by an example.

0800:400:20:20 and 0905:400:20:20. Application of IBM Procedures to Production Control; *Lassing, James Singleton; Department of Industrial Engineering, University of Tennessee, Knoxville, Tennessee.*

The purpose of this study was to investigate the ways in which IBM procedures and equipment might profitably be used to control a manufacturing process. It was found that IBM systems can provide records necessary for planning; specifications for products, assembly and fabrication, and purchases; shop records; and control documents and reports. However, it was also found that the benefits derived might not justify the cost, especially in plants with a small volume of production or non-repetitive type transac-

tions. It was concluded that although there are certain characteristics which indicate the advisability of an IBM installation, there is no substitute for a detailed study to determine the best system for a particular plant.

0720:400:40:40. Electroplating 22 Karat Gold-Silver Alloy; *Harr, R. E., and Gafferty, A. G.; Development Engineers, Western Electric Co., Hawthorne Works, January, 1958;* **Metal Finishing.**

Deals with the laboratory development of plating solution parameters and process controls which insure that electro deposition of an 85 silver-gold alloy falls within narrow control limits. The plating is designed to increase the reliability and service life of electrical wiping contacts. This paper was judged by Technic, Inc. to be the best on the plating of precious metals in 1956.

0855:000:30:20. An Experimental Investigation of Scheduling for Single-Stage Production; *Conway, Richard W.; February, 1958; Cornell University Library, Ithaca, New York.*

Development of a digital simulator to study a single-stage process with multi-product, deterministic demand; with storage and penalty costs, and with variable set-up costs depending on sequence. Development of suitable priority rules is discussed and response of the process to certain rules under various load and cost conditions is studied by use of the simulator.

0720:000:20:20. Industrial Applications of Radioisotopes; *Kelly, Robert C.; June, 1954; University of Tennessee, Department of Industrial Engineering, Knoxville, Tennessee.*

The object of this study was to ascertain the extent to which radioisotopes are being used in industry, the applications for which they are being used, and whether they are proving to be satisfactory for the intended applications. The information used in this study was obtained primarily from personal interviews, published literature, and from a survey of 51 industrial users of radioisotopes.

0925:000:20:20. A Method for the Simultaneous Design of Inputs, Outputs, and Program for an Automatic Typewriter in an Integrated Data Processing System; *Homer, Eugene D.; September, 1958; Library, College of Engineering, New York University, University Heights, New York 53, New York.*

This paper describes a method of programming an automatic typewriter which yields close to optimum results with a minimum of trials, by the simultaneous design of the program and the printed and punched documents. The integrated planning of these factors provides for the consideration of demands made by forms design, by subsequent usage of tapes, by specific equipment characteristics, and by personnel requirements at every step of the operation. Two new planning charts are described: a Data Flow Chart, and an I.D.P. Program Planning Chart.

1010:000:20:20 and 1025:000:20:20. An Empirical Investigation of Queue Characteristics with Weibull Arrival and Holding Time Distributions; *Ackerman, Sanford S.; September, 1958; Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.*

The author is concerned with the effect of violations of the Poisson-arrival-time and exponential-service-time assumptions in the analysis of queues. Monte Carlo methods are used to study the behavior of a single queue being served by a single server with no priorities or restrictions on the length of the queue, under arrival and service time distributions which are not governed by Poisson processes, but by Weibull processes. Deviations of these distributions from the Poisson or exponential distributions are measured by considering the Weibull scale parameter, which has the value I under the Poisson assumption.

1010:000:70:20 and 1025:000:70:20. A Monte Carlo Analysis of Certain Types of Waiting-Line Problems; *Pisaneschi, Merle L.; 1958; Engineering Library, Engineering Hall, University of Pittsburgh, Pittsburgh 13, Pennsylvania.*

This research is an experiment on certain classes of waiting line problems involving servicing facilities. The data utilized in the analysis are not real in the sense that these data were gathered from actual experience but rather are simulated data generated by the Monte Carlo technique.

0910:000:30:20 and 1005:000:30:20. Programming under Uncertainty; *Elmaghraby, Salah Eldin A.; September, 1958 Cornell University Library, Ithaca, New York.*

After a brief review of criteria for decision and the notion of utility the allocation problem in the case of a continuous demand distribution is discussed, a necessary and sufficient condition for optimality given and an iterative algorithm for solution provided. The general programming problem with discrete demand distributions is also treated. An analytical solution of the game-theoretic interpretation of programming is presented where the probability frequency function of demand is estimated by means of an interval. Study of feasibility of solution by an analog computer is also made.

1000:500:60:60 and 0855:500:60:60. A Study of Newspaper Local Display Advertising Composition; *Bevans, Carville G.; Warner, Donald G.; Tewlow, Jules; Kues, Irvin W.; Brenner, Michael; Davidson, Sidney; Roy, Robert H.; Shaffield, J. H.; February, 1958; American Newspapers Publishers Association Research Institute, 140 South Dearborn Street, Chicago 3, Illinois; "A Case Study in Newspaper Operations" by Sidney Davidson and Robert H. Roy, to be published in* **Operations Research and Systems Engineering.**

A study of the operations involved in the composition of newspaper local display advertising as resulted in a 3-Variable model which predicts composition time with considerable accuracy. The general form of the model has been applied to operations in some 30 newspapers all over the country. It permits internewspaper comparisons, job cost accounting, measurements of production efficiency, and analysis of advertising rates in a manner which has not hitherto been possible. Further studies, comparing composition by the conventional hot metal process with composition by the emerging processes of photo-composition are being carried forward.

0520:300:20:20. An Analysis of the Economics of Earth Moving; *Dodge, Roy T.; June, 1958; Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.*

Various types of earth-moving equipment are analyzed and the pertinent costs associated with earth moving and the ownership of earthmoving equipment are discussed. The efficiency and costs for various lengths of haul and quantities of earthmoving are given; and finally, an analysis of four major construction jobs is given insofar as the earthmoving requirements are concerned.

0615:000:20:20 and 1120:000:20:20. Control of Procedural Costs in Administrative Overhead; *Jewett, David M.; June, 1959; Department of Industrial and Engineering Administration, Upson Hall, Cornell University, Ithaca, New York.*

An outline of major problems in area and suggestion of a procedure designed to control such costs. The procedure includes discussion of the organization required, standardization, methods used in procedural studies, budgeting, and forms development.

1205:000:30:20. The Application of Mathematical Techniques in the Field of Industrial Engineering; *Dudek, Richard A.;*

June, 1956; Engineering Library, State University of Iowa, Iowa City, Iowa.

Survey of mathematical techniques in use in Industrial Engineering applications in progressive industry. Consideration of curriculum requirements in preparing engineering students for maximal use of these techniques.

1220:000:20:20. Analysis of the Relationship between Attainments of Engineers while in School and Accomplishments after Graduation for the Classes of 1922-27; *Miller, David C.; August, 1940; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

In this two-part study, part I presents data describing the economic, occupational, and social status of the engineering graduates in the classes of 1922-27. Part II aims to discover factors contributing to occupational success by studying the relationship between attainments in school and accomplishments after graduation.

1205:000:20:20. The Design of an Industrial Engineering Curriculum; *Jarrett, McRae; March, 1959; University of Tennessee, Department of Industrial Engineering, Knoxville, Tennessee.*

This thesis concerns itself with the problem of designing an Industrial Engineering curriculum which takes cognizance of the trends in engineering education, the recommendations of the Engineer's Council for Professional Development, and the desires of industry. An undergraduate Industrial Engineering program is proposed and is evaluated in terms of the recommendations of the Engineer's Council for Professional Development. An attempt is made to appraise the proposed program's ability to fill the needs of industry as expressed in some recent surveys. The program is compared to existing curricula at other institutions.

1215:000:30:20. The Relationship of Test Scores to Scholastic Achievement for 244 Engineering Freshmen Entering Purdue University in September 1939; *Johnson, Albert P.; May, 1942; Inter-Library Loan Service, Purdue University, Lafayette, Indiana.*

This thesis is a broad scale exploratory study to define a typical student entering freshman class in terms of mean scores and score ranges on a wide variety of psychological and physical measures and of personal data, and to discover that combination of measures and items making possible the best prediction of scholastic attainment for the chosen typical group.

PRESIDENT'S COMMENTS . . .

by **ALEX W. RATHE**

President of the American Institute of Industrial Engineers, 1960-61

Management Control and Industrial Engineering[1]

WHAT is "control"? Control is a, possibly *the,* key element in management. Consequently, there are many managerial techniques which aim at the control of every important component within the many man-machine subsystems which management intermeshes in the operations of the organization—labor and materials, safety and finances, production and processes, etc.

Similarly, many everyday occurrences in life concern

[1] For the earlier parts of this series, refer to (1) (2) (3).

themselves with control—of rents or traffic, parking or heat, currency or pests, and many others.

In every one of the possible examples, "control" has a somewhat different meaning. It signifies at one time or another the task to:[2]

.. account
.. act
.. administer
.. boss
.. check
.. command
.. compare
.. correct
.. curb
.. direct
.. dominate
.. drive
.. enforce
.. expose
.. fit
.. forestall
.. guide
.. hinder
.. influence
.. join
.. judge
.. know
.. lead
.. manage
.. manipulate
.. measure
.. negotiate
.. number
.. object
.. observe
.. overpower
.. persuade
.. prevail
.. prohibit
.. quantify
.. question
.. regulate
.. reprove
.. restrain
.. rule
.. shackle
.. supervise
.. suppress
.. test
.. unite
.. uphold
.. verify
.. warn
.. watch
.. weigh

Why do we have so many different meanings for a thing as common-place as control? Two facts appear to be mainly responsible for this phenomenon:

.. 1. Language always reflects the thinking of the people who use it.

.. 2. The approach to control has changed a lot over the centuries.

The term "control" thus mirrors the many shapes which it has worn in past practice.

The most important common element in all these different controls is *force*, with the connotation of control *over* somebody or something, of a repressive or oppressive action, of a penalty. This inference of punishment is a burdensome heritage which bygone generations have left to us in the twentieth Century. Ideas and behavior which have been shaped under the impact of events of hundreds of years do not adjust quickly. Today's business operations are therefore, in a number of cases, not as far removed from the climate of olden days as the time which has elapsed seems to promise.

Let me make it unmistakably clear:

.. I am of course not taking a stand against control *as such;* it is one of the most important ingredients in the success of any managerial or engineering project.

.. However I wish to object emphatically to the *way* in which control is permitted to evidence itself in too many instances.

[2] For a more extensive discussion of this and several subsequent thoughts, refer to the chapter on "Management Controls in Business," by Alex W. Rathe (4).

Control still continues, in numerous spots, with more tradition-treasured trappings than any other part of management. It would be much more effective if it cleansed itself of its medieval shackles. Its purpose is to assure desired results. Its mission is to provide means toward that end, not to be an end in itself.

The crux of control has been, is, and will continue to be the obligation to keep things on the beam—to hold the reins—to see that the original plans are accomplished and that appropriate action is taken if they are not.

Thus control is the end result of a process which requires that:

.. First, we have to know what results are needed; then we must arrange our available resources in such a manner as to be able to utilize them most effectively in the pursuit of this goal. The custom of progressive managerial practice today is to lump the sum total of these efforts together under the label "planning";

.. Secondly, these plans are put into effect; activities are directed so as to take maximum advantage of the planning blueprints. Modern terminology generally applies the name "operations" to this phase.

.. Thirdly, operations are observed; what is actually happening in the activities covered by the plans, is recorded. These soundings are analyzed so as to distill from them the reasons why one or the other phase is not proceeding as planned. Conclusions are drawn as to what remedial action may be needed under the circumstances. (These ideas are fed back to the first phase, "planning," where they are dovetailed with plans which exist or are in preparation for the future, for immediate or delayed execution as the situation demands.) This third element is ever more frequently referred to as "review."

Obviously we deal here with a loop, just as engineering and management were briefly sketched in the preceding part of this series (3) as being performed in a cycle.

If "control" is meant in this, its most expansive scope, it is synonymous with "management." The system components described above as "planning," "operations," and "review" are precisely the same through which we described "management" before.

At the other end of the scale which plots the varying meanings of "control," we find it identified only with the third phase, namely with "review." If we study the instances in which control has secured favorable results but also caused significant difficulties, we discover that, in most cases, they were situations which tolerated a wider scope, that control was permitted to trespass upon operations by *diluting or contradicting assigned operational responsibility.*

In management as well as in engineering, practice seems to dictate, beyond the shadow of a doubt in the light of evidence accumulated so far, that control must strictly differentiate between its role in:

.. pinpointing deviations from expected results and their analysis ("review" or "test"),

.. fitting these conclusions in with existing or new plans ("planning" or "specifications"),

.. executing them ("operations" or "design").

Comparisons with experience gathered in the fields of

Control and Systems Engineering and with knowledge of parallel action in the human brain show encouraging agreement upon the validity of these conclusions. The main difference between these fields on the one hand and management on the other is the fact that in the former the cyclical process is often automated, i.e. it proceeds in a closed loop. For better or worse, this is not the case in management. Here the feedback of review conclusions into plans is a link which is generally not yet coupled to other program guides. It is usually a weak link, in most cases the weakest in the cycle.

THE ANATOMY OF REVIEW

If we examine available control techniques, we find that most if not all of them fall squarely within the boundaries of review. We also recognize at once that Industrial Engineering has, as in planning, made generous contributions to the executive review kit.

Although this Anatomy of Review is presented in much too few lines, we can summarize its mission as:

.. 1. measuring of performance:
Operations—wherever they take place—are observed; results are recorded; data are checked and sorted, classified and summarized, trended and recapped or arranged in still other fashions so as to facilitate the second part, namely:

.. 2. evaluation of this information for the purpose of enabling us to draw conclusions on what changes in past or future plans appear advisable in the light of this operating experience.

This appraisal or analysis aims at making it possible for the symptoms which were just recorded to be interpreted in terms of their meaning; it transforms the knowledge of the effects from operations into a recognition of the causes which produced them; it permits the facts which are indicated by the recording instruments to become spokesmen for suggested changes whose realization will, we hope, bring the results originally intended.

We can expect to recognize among review techniques some which perform measurements and others which are devoted to analysis; several of the available tools serve both purposes.

In presenting a sampling from these, a few thoughts on the problems of measurement and of analysis will precede their discussion.

YARDSTICKS OF MANAGEMENT

Knowing how to make measurements has been among the engineer's most time-honored assignments. For the Industrial Engineer, this obligation identifies his concern with the measurement of any influence which can make itself felt in managerial problems. This covers a large territory. We need yardsticks for:

.. input and output;
(for example, quantity of material supplied to a process and the resulting production volume);

.. cause and effect;
(such as population changes and their impact on economic fluctuations);

.. the total system and its parts;
(net return on investment gives an overall measure; specific cost items address themselves to just one part);

.. material (such as time) and human components, with the latter present again in two forms, namely—
individuals (fatigue)
and groups (morale).

Looking again at this assembly of measuring problems but from another angle, we should distinguish also for instance:

.. between absolute and relative measure;
(quantity, quality, distance, value, etc. versus efficiency, frequency, etc.);

.. between yardsticks at transfer points along an often long line from input to output;
(A useful measurement system must provide, for example, the answers to what happened to a ton of steel tubing since its arrival on the receiving platform—input—, in raw materials stores, during each production process, while it is being moved from one operation to the next, until it leaves the factory in final shape in the completed product—output.)

.. measures of the resources at hand and of their exploitation;
(Suppose review reports an unsatisfactory result. Was this caused by bad plans despite superb efforts in their execution? Or was it the effect of slip-shod operations although the plans were excellent?)

.. perhaps most important, indicators of the performance of one individual activity and of its contribution to the overall organizational effort.
(I recall the experience of a printing plant within a large food processing concern whose new manager gradually put a traditionally red ink performance into the black. He accomplished this by scheduling his runs to yield minimum printing cost and through other fine innovations. However, the profits of the print shop for five full years went down the drain in three days when several canneries which it supplied with brand name labels had to shut down for 72 hours because the printer's shipping schedule had not been synchronized with their needs.)

Many yardsticks are in current use in business practice. In some fields, they are firmly accepted; witness the wide use of financial and cost data provided by accounting and the important place which they occupy in so many organizations. On the other hand, there is desert barrenness in other areas.

In the arena of performance measures, Industrial Engineering has a triple entry. There is first: work measurement; it gauges work output in terms of *time* (through Ratio Delay, Individual Stop Watch Studies, Standard Unit Times and other approaches). Then there is production control which measures *quantities* of output (in terms of production volume or production rate or efficiency, inventory, or turnover, equipment capacity or utilization, etc.). And inspection, by sorting output according to *quality*, adds performance measures through the recording of (initial) defectives, their division into rework and scrap, malfunction rates and dozens of other gauges.

The contributions by Accounting and Industrial Engineering furnish management with a generous (although far from exhaustive) supply of material measures. Among

those which are conspicuous by their absence are personnel measures.

Yet this is an area which is of topmost significance in management and thus to the Industrial Engineer. The key characteristic of any managerial problem is the ever-present influence of the human element. Nothing whatsoever happens in management, including the most extensively automated operations, in which people are not the key link to machines or markets, money or methods, in one way or another. (For instance, it is not "the market" as a theoretic abstraction but as an accumulation of customers, which refuses to buy our new product.) As Industrial Engineering is dedicated to the task of designing sizable if not all segments of the way this management system works, availability of factual information on its human components is a must.

The development of more and better indicators and the manner in which these data are being processed are therefore two opportunities in which Industrial Engineering will become ever more active during the years to come. Availability of such performance measures will be aided considerably by the progress which computers are making in their role as programmers of activity and as recorders of results.

To keep this growth within manageable and practical bounds is a major problem. Management does not want just more and more figures; it needs more and more *meaningful* information—wherever possible, in numerical form.

This is an endeavor in which we can expect increasing links to other disciplines which, like the behavioral sciences and economics, have begun to make promising inroads toward the solution of these matters. Well advanced beyond preliminary laboratory experience are, for example, the social scientists' successes in the measurement of:

.. identification of workers with company objectives,
.. the level of motivation and its effect on waste and cost reduction, on the concern with improvement of product and process, on the degree of confidence in each other and management, on the effectiveness of delegation and communications, etc.

Economists and mathematicians, operations researchers and management scientists constitute but a selection from an even larger circle of people who are currently devoting sizable effort to the creation of practically useful performance measures in management. Decades ago, the Industrial Engineer led the field through his monumental contributions to work measurement. But he has not kept his original zeal in the further development of indicators which provide similarly useful results beyond repetitive routine work, for instance, in creative tasks. Too many important sectors of managerial concern are labeled "intangible" simply because we do not yet know how to measure, say, the value of a trademark or a patent, of good will, of engineering knowledge and its contribution to executive success, or of results from training sessions.

Industrial Engineering would let a mangnificent opportunity go unused if it does not buckle down soon to extend the heritage of its own early accomplishments in the fields of measuring time and quantity and quality. When these were made, they were revolutionary; and they were sufficient because the scope of managerial concern rarely went beyond them and beyond those involved in cost accounting. But this was thirty and fifty years ago. The magnitude of management responsibility today demands the expension of these pioneering efforts to cover the full range of the vastly increased number of facts which we now know influence performance.

Contemporary leaders in this stage of accomplishments have laid the groundwork through the development of management review data in any imaginable type of activity. One outstanding example is General Electric's Measurement Project. It suggests that there are seven "key result areas" in an industrial enterprise, namely:

.. profitability,
.. market position,
.. productivity,
.. product leadership,
.. personnel development,
.. employee attitudes,
.. public responsibility.

For each of these, management is attempting to develop factual measures of all or at least of the key components. Sizable progress has been made to date, in relatively few years. Much remains to be done, including increased participation of engineering know-how on behalf of the solution of the balance of these problems.

FACTS AND BASES FOR ANALYSIS

Measures mean nothing by themselves. They earn their livelihood only to the extent to which they facilitate the interpretation of the events upon which they report. Whether a 32% increase in last month's selling expense—factually recorded, through proper instrumentation, over the corresponding period last year—is something good or bad or indifferent, can not be established without considering this fact within the framework of:

.. the plans which had been made for these activities and
.. the results which they were expected to produce.

Managerial practice is gradually recognizing the great difference which exists between the mere presence of records chuck full of performance measures upon an operation and the skillful interpretation of the meaning which these measures contain for those who know how to extract it. The latter represents a decisively larger challenge to creative talent. Its magnitude is perhaps properly reflected by the fact that four distinct trends are at work simultaneously.

The first shows itself in the extension of existing measurement techniques into the appraisal area. Several have made encouraging progress along this line. Taking the younger one first because of its familiarity to a wider

circle of readers, may I invite your attention to the developments which have brought such deserved prominence to quality control as a logical supplement to inspection.

The latter provides, through its data on work quality, the raw material for the former. Quality control begins its work where inspection leaves off. It takes the information on output quality and other matters for the purpose of analyzing them so as to unearth the reasons why quality standards were not adhered to in operations.

For example, cost data on inspection work are studied to explore the need for 100% inspection as against the desirability of designing (and using) a sampling plan. Or statistics on percent-defective are diagnosed (through an examination of existing product specifications, machine and process capability studies and other means) so as to arrive at recommendations to revise piece tolerances, change machine setup, introduce process control—there is that word again!—or of a still different character.

Long before quality control was born, a similar development had placed financial audits onto the financial segment of the management review scene as the analytical companion to accounting. And in more recent years, personnel appraisals have made their appearance as an extension of personnel measures. Without seeming to acquire a new name for this extended scope of its interest, production control is currently in the process of pushing beyond the generation of factual data on quantity, by extending its boundaries to include their appropriate analysis.

All these trends answer the need of review for follow-through on the production of data with an analysis and interpretation of their meaning. But all of them are limited, by the very nature of their beginnings, to one specific aspect of the total picture, be it finance or cost, time or quality or quantity.

At a time where the systems approach has finally started to gain the stature it ultimately deserves, a view of the complete scene can not be attained by any piecemeal approach—important as each is in its realm. Therefore special importance is attached to the evolution of management audits. Their mission prescribes the use of an overall view, of a systems-oriented analysis on the strength of a lineup of all pertinent measures.

A management audit evaluates performance for the purpose of suggesting how it can be improved in the future through appropriate planning changes. Its focal point is the work itself in relation to the sum total of all activities. The man who caused it to be done or did it is one component in the system. His contribution is important in terms of the value which his effort added toward the accomplishment of the goals set for his activity in the full picture. The emphasis is, in contrast to personnel appraisals, placed on achievements in terms of results, not on traits of the individual who brought them about or failed to do so. Obviously these characteristics are or could be important, but only to the extent that they were causes for the effects which go beyond the person himself.

This is still virgin territory. But it is a field of most pronounced promise. It demands Industrial Engineering attention if it is to be further developed into a useful contribution by engineers to the solution of managerial problems.

Statistical techniques represent the second important trend. This is a natural one as they are *the* analytical tool of science. Their effectiveness has strengthened not only industrial but many other branches of engineering just as soon as each has recognized the enormous impact which is inherent in them.

Emphasis on more facts is producing a larger procession of numerical indicators on the executive instrument panel. Thus mathematical treatment has become possible for many problems which used to be decided through hunch or guess or, at best, through some experience-rules-of-thumb.

Industrial Engineering is certain to avail itself of ever more mathematical and statistical techniques in the future. All of them, though, are likely to be applied with the keener sense of selection which the wisdom of hindsight accelerates. Today, mathematics and statistics are still too often abused by providing more precise answers not of solutions but of errors in the assumptions. Unless numbers can be attached to managerial events with reasonable certainty that they reflect operational reality and not just wishful trend-extrapolation, their mathematical or statistical treatment is doomed to distort relationships in fulfillment of a mission which claims clarification as its objective.

A third development hinges around the computer. Its capabilities can respond to the needs of managerial review with as amazing results as they are serving the planning phase of an electric power utility, an assembly line, a materials stock room, payroll records, oil refinery schedules and dozens—yes hundreds and soon thousands—of other applications. Under a 1961 dateline—and the speed of progress cautions me to qualify this even further by stating that these lines are dictated in November, 1960—it is proper to admit that the abilities of computers are far from being fully utilized in managerial control.

Research provides the fourth trend which is evident in its impact on current developments of managerial review. As the next part of this series will address itself specifically to the research area, I should like to request the readers' indulgence when I postpone a further discussion of the roles of computers and of research for the following issue.

THE SCOPE OF REVIEW

Ideally the respective scope of planning and of review should be exactly the same. It would make little sense to plan matters without ascertaining how they come out. Nor would it be a very sensible or economic undertaking

to make measurements and analyses for areas which will not be utilized in future planning.

But in managerial practice there is a very real difficulty in fulfilling this premise of co-extensive co-existence of planning and review. It stems from the different origins of the techniques which we use in these sectors and in their, as yet, entirely unplanned development. All older measures are strictly "functional," i.e. they gauge cost or quality or some other specific factor. Many planning tools already cut across several considerations; for instance, good operating programs and long range plans wrap all influences on performance together.

While control is probably the older of the two, planning, because of its relative youth, could embrace this systems approach at an earlier stage of development. This discrepancy hampers the interplay between the two.

Therefore, of much greater importance is the fact that review has shared with planning the same fate in terms of expansion into ever-wider fields. As discussed in the preceding portion of this series with specific regard to methods engineering (3), we find that many review techniques, though originating with the factory, have pushed well beyond manufacturing and are now used in any activity or operation, any type of commercial or government or any other kind of enterprise.

PROGRESS WIDENS INDUSTRIAL ENGINEERING HORIZONS

Industrial Engineering's occupation with control tasks in management focuses attention upon the developments in another profession, namely Accounting. There the controller has recently scrutinized his role as one of management's mainstays with similar urgency as we are examining ours. As a result, the past ten years or so, have seen controllers increasingly concerned with organization-wide planning, with performance review and analysis. This brings up the interesting question of our relationship to those who have embraced this truly enlightened concept of modern controllership. The answer seems to be precisely the same as that which the Industrial Engineer has given to cooperation with other specialists.

Just as we have teamed up with statisticians and mathematicians, with psychologists and sociologists, with physicians and lawyers in the interest of bringing the joint impact of our respective knowledge to bear upon managerial problems, so does partnership in many tasks of the controller appear as another facet of Industrial Engineering's future. We owe the very existence of our branch of engineering to the seemingly eternal growth of specialization. With it goes, as an inevitable corollary, the need for ever-wider teamwork.

Whether a profession proceeds by itself in the splendor of isolation or joins hands with others so that united effort in the pursuit of common objectives will bring greater results, the aim is *progress*. We can not progress if we don't remedy the errors of the past.

To help us recognize them is the task of review. To put this experience to work is the aim of control. Both are needed for progress because those who can't learn from the past are condemned to repeat it.

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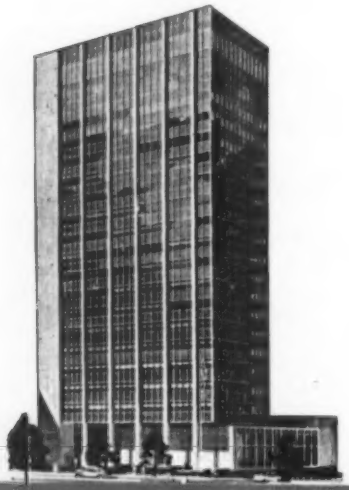

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